

Technical Report 1097

Applying Digital Technologies to Training: A Focus on Pictorial Communication

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September 1999

19991020 131



**United States Army Research Institute
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REPORT DOCUMENTATION PAGE

1. REPORT DATE (dd-mm-yy) September 1999		2. REPORT TYPE Final		3. DATES COVERED (from... to) Oct 96-Oct 98	
4. TITLE AND SUBTITLE Applying Digital Technologies to Training: A Focus on Pictorial Communication				5a. CONTRACT OR GRANT NUMBER	
				5b. PROGRAM ELEMENT NUMBER 0602785A	
6. AUTHOR(S) Carl W. Lickteig (U.S. Army Research Institute) and May H. Throne (University of Louisville)				5c. PROJECT NUMBER A791	
				5d. TASK NUMBER 2228	
				5e. WORK UNIT NUMBER H01	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Institute for the Behavioral and Social Sciences ATTN: TAPC-ARI-IK 5001 Eisenhower Avenue Alexandria, VA 22333-5600				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Institute for the Behavioral and Social Sciences 5001 Eisenhower Avenue Alexandria, VA 22333-5600				10. MONITOR ACRONYM ARI	
				11. MONITOR REPORT NUMBER Technical Report 1097	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES May H. Throne is a graduate student at the University of Louisville working as a Consortium Research Fellow at the U.S. Army Research Institute's Fort Knox Research Unit.					
14. ABSTRACT (Maximum 200 words): Digital technologies can help solve many of the training problems they create. The Army's investment in digital technologies assumes that they will portray a common picture of the battlefield on the digital displays of warfighters and supporters, and improve training. This report focuses on the application of digital technologies, such as instrumented command and control systems and military simulation, to train the skills to understand and maintain a pictorial depiction of the battlefield situation on digital displays. Three main areas of research are identified that focus on common picture training and evaluation requirements: define, communicate, and maintain a common picture of the battlefield. For each of these areas, research issues are raised and corresponding training and evaluation methods are recommended to address each issue. Overall, the method recommendations repeatedly examine how a log of soldier-computer interactions from instrumented command and control systems can automatically provide an empirical base for assessing performance and giving feedback. Conclusions consider how integration and implementation of the training and research methods recommended in this report, in concert with digital technologies, might foster design and development of a digital training environment directed at the pictorial communication of battlefield situations on digital displays.					
15. SUBJECT TERMS Human Performance C ⁴ I Digital Technologies Training Simulation Pictorial Communication					
SECURITY CLASSIFICATION OF			19. LIMITATION OF ABSTRACT Unlimited	20. NUMBER OF PAGES 81	21. RESPONSIBLE PERSON (Name and Telephone Number) Dr. Carl Lickteig DSN 464-6928
16. REPORT Unclassified	17. ABSTRACT Unclassified	18. THIS PAGE Unclassified			

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September 1999

**Army Project Number
2O262785A791**

Education and Training Technology

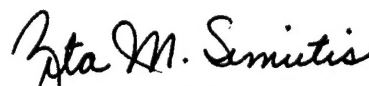
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FOREWORD

The Army's growing reliance on digital technologies reinforces and extends concerns about skill acquisition, retention, and transfer. Digital information technologies affect job performance and generate new training issues and problems. This report describes how digital technologies can help solve the training problems they create.

This report recommends an integrated set of methods that apply digital technologies, such as instrumented command and control systems and military simulations, to train the skills needed to understand and maintain a pictorial depiction of a battlefield situation on a digital display. These method recommendations address the need to define, communicate, and maintain a common picture of the battlefield situation across warfighters and supporters. The application and integration of such methods should help the Army design and develop digital training environments for an information age force.

This research was part of the U.S. Army Research Institute (ARI) for the Behavioral and Social Science's program to train the force. The objective of ARI's Future Battlefield Conditions (FBC) team at Fort Knox is to enhance soldier preparedness through development of training and evaluation methods to meet future battlefield conditions. This report represents efforts for Work Package 2228 Force XXI Training Methods and Strategies (FASTTRAIN). Results of this effort have been shared with other ARI units engaged in similar efforts and the Fort Knox Test and Experimentation Coordination Office (TECO). A Memorandum of Agreement (MOA) with the U.S. Army Armor Center (USAARMC) supports ARI's research on training requirements and evaluation methods. This MOA is titled Manpower, Personnel and Training Research, Development, Test, and Evaluation for the Mounted Forces, 16 October 1995.


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Technical Director

APPLYING DIGITAL TECHNOLOGIES TO TRAINING: A FOCUS ON PICTORIAL COMMUNICATION

EXECUTIVE SUMMARY

Research Requirement:

To achieve the Army's information age objectives, training and evaluation methods are required to improve soldier-computer performance. Digital technologies, such as instrumented command and control systems and military simulations, afford unique training solutions. The research requirement addressed in this report is how to apply digital training solutions to address training and evaluation concerns.

Procedure:

This report's approach focused on the Army goal to apply digital technologies to provide a common picture of the battlefield to warfighters and supporters, and improve training. To address this requirement, Army modernization objectives, efforts, and lessons learned were reviewed. A review of training literature identified shortcomings in learning theory and practice, and barriers that restrict the application of technology to training. This review stressed the relatively unique ability of digital technologies to pictorially represent battlefield situations and the mental models of trainees, and perceptually link these representations to train pictorial communication. Digital training implications, both theoretical and practical, were examined to balance training and evaluation efficiency and effectiveness.

Findings:

The findings are a recommended set of training and evaluation methods that apply digital technologies to the skills needed to understand and maintain a pictorial depiction of a battlefield situation on a digital display. These method recommendations address the requirement to define, communicate, and maintain a common picture of the battlefield shared by warfighters and supporters. For each of these requirements, research issues are raised and corresponding training and evaluation methods are recommended to address each issue.

The method recommendations stress an empirical approach to training and evaluation. Method recommendations repeatedly examine how a log of soldier-computer interactions from instrumented command and control systems can automatically provide an empirical base for assessing performance and giving feedback. Conclusions consider how integration and implementation of the training and research methods recommended in this report, in concert with digital technologies, might promote the design and development of a digital training environment. Key training and evaluation considerations for this environment focus on the need to pictorially communicate the battlefield situations depicted on digital displays.

Utilization of Findings:

The methods recommended in this report should help training and evaluation researchers improve soldier-computer interaction and foster the skills needed to understand and maintain a pictorial depiction of a battlefield situation on a digital display. Method implementation will require coordination efforts between these researchers and the developers of training, training simulation, and digital systems to help the Army design and develop a digital training environment that provides the skills required for an information age force.

APPLYING DIGITAL TECHNOLOGIES TO TRAINING: A FOCUS ON PICTORIAL COMMUNICATION

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APPLYING DIGITAL TECHNOLOGIES TO TRAINING: A FOCUS ON PICTORIAL COMMUNICATION

INTRODUCTION

The U.S. Army's ongoing modernization plan presumes force dominance depends on advanced information technology. The Army envisions a digital battlefield on which all warfighters and supporters are networked by digital information systems, referred to here as Command, Control, Communication, Computer and Intelligence (C⁴I) systems. The predicated military capability of C⁴I systems is epitomized by their ability to portray a common and relevant picture of the battlefield situation. To achieve the Army's information age objectives, such as a common picture of the battlefield, training and evaluation methods are required to improve soldier-computer performance.

To address this requirement, this report identifies a set of research issues and provides corresponding method recommendations to help realize the potential of C⁴I systems. These issues and methods are based on a literature review summarized in the background and method sections. A particular focus, perhaps bias, of this review was how to apply digital information technology to meet C⁴I training and evaluation requirements. In other words, an assumption of this report's authors and much of the literature reviewed is that computers can help solve many of the training problems they create.

This report's approach begins by considering the profound impact of advanced information systems, particularly digital technologies, on job performance and training in commercial and military organizations. One notable impact is a perceived lag in the application of advanced information systems to training. Another impact is that advanced information systems designed to aid job performance, often burden, frustrate, and misinform workers. Reasons for such negative impacts are reviewed with special emphasis on reasons related to inadequate methods for training and evaluating computer-mediated work.

The Army requirement for training and evaluation methods directed at the digital battlefield of the future is also reviewed. The Army's expectations for a digitally equipped force and lessons learned bearing on these expectations from related Army research are considered. The slant of this review focuses on the Army's expectation that C⁴I systems should provide warfighters and supporters a "common picture" of the battlefield. This common picture concept is discussed as a challenging but defining objective of the Army's investment in advanced information systems. To help address this objective, this report focuses on training and evaluation methods directed at the pictorial communication of battlefield situations.

For this report, pictorial communication means that a C⁴I display should convey needed battlefield information in picture formats the user can satisfactorily receive, understand, and act on. This report's pictorial focus stresses the Army's expectation that C⁴I systems should literally depict a picture of the battlefield, a visual image or illustration of the battlefield situation. While textual and tabular formats may be needed for additional detail, a pictorial representation of the battlefield situation is a foremost concern. A telling expectation is that a C⁴I display will convey "at a glance"

the user's battlefield situation. The report's focus on communication stresses that when the worker's tool is an information technology, communication between that tool and the worker is critical to their collaborative performance, such as creating and maintaining a picture of the battlefield that transfers goal-relevant information.

The intent of this report, therefore, is to identify and capitalize on research methods that could apply advanced information systems to training and evaluation efforts directed at the pictorial communication of battlefield situations. The authors readily acknowledge the cited work of others used to develop the methods recommended. The contribution of this report, at best, is to document how the methods reviewed might be adapted and integrated to help the Army meet some important C⁴I training and evaluation requirements.

The background section reviews more global training issues and methods. In the background, for example, barriers are identified that deter the application of training technology. These barriers include a project versus program approach to training development, and a failure to apply more unique medium capabilities. Another barrier may be an approach to training that regards training content as an external, physical reality to which course delivery conditions trainee performance. In contrast, more contemporary training approaches are considered that match training content to what trainees already know.

The background section examines the relatively unique ability of digital technologies to emulate microworld work models, such as a battlefield situation depicted on a C⁴I display, and the mental models of trainees and users. Digital training methods to perceptually link these models are considered for training pictorial communication. Finally, some practical implications of digital training are examined, to balance training effectiveness and efficiency concerns.

The method section reviews and recommends training and evaluation methods for three main areas of research directed at the pictorial communication of battlefield situations on C⁴I displays. These research areas are centered on common picture training and evaluation requirements: define, communicate, and maintain a common picture of the battlefield. For each of these areas, a set of research issues is identified and corresponding training and evaluation methods are recommended to help address the issues raised.

The methods recommended are based on the authors' review of related methods and the relatively unique capability of digital information systems, such as instrumented C⁴I systems and military warfighting simulations, to synthesize training and evaluation. The method discussion provides a more detailed description of the methods reviewed or directs the reader to descriptions available in the literature. The method recommendations adapt the methods reviewed to devise a relatively integrated set of training and evaluation methods that directly address the research issues under each of three research areas identified.

Key research issues to define the common picture include the need to: develop conceptual and operational definitions of the common picture objective; determine user information requirements; assess C⁴I capabilities against user information requirements; and, assess performance and give feedback. Corresponding method recommendations begin with a working

definition of the common picture based on relevant aspects of Mission, Enemy, Terrain, Troops, and Time (METT-T) on a C4I display. Recommended methods for developing an operational definition stress the need to scope the problem. Problem bounding methods focus on information requirements for structured battalion and brigade exercises at duty position level matched against information capabilities for a battalion and brigade level C4I system. To identify user information requirements, method recommendations for eliciting user and expert knowledge stress a process trace of those requirements during simulated exercises. Methods for assessing C4I capabilities against user information requirements that result in C4I display codes are described. Most importantly, this section describes how instrumented C4I systems can automatically analyze the collaborative process required to develop the common picture depicted on users' C4I displays at any point during a unit's training exercise.

Key research issues identified under communicate the common picture include the need to: shape C4I representations to match users' mental models and, subsequently, shape users' mental models to match C4I representations. Corresponding method recommendations to shape C4I representations, first assess how well C4I systems pictorially communicate meaningful information to the user. Second, research methods are recommended to assess communication tradeoffs between the Army's analog information formats versus the digital formats available from current and future C4I systems. Method recommendations to shape users' mental models to match C4I representations correspond to individual training methods for pattern and situation recognition. These methods capitalize on the ability of digital technologies to provide trainee and trainer control over transformations in the tactical patterns and battlefield situations depicted on C4I displays. A variety of methods to control or manipulate training presentation formats are described including: a reduced stimulus environment, animation, perceptual augmentation, and time compression and expansion. Additionally, the recommended methods for shaping users' mental models to match C4I representations rely on documented methods for developing automatic processing capabilities to recognize tactical patterns and situations.

Key research issues identified under maintain the common picture include the need to: develop a model of information exchanges required to maintain a common picture; link this communications model to military simulations and C4I systems; and, apply these integrated digital technologies to training at individual, small group and collective levels. Corresponding recommendations first describe methods for developing expert and machine versions of a common picture communications model. Then, training implications are examined based on linking this communications model to constructive, virtual, and live warfighting simulations. Finally, training method recommendations for individual, small group, and collective levels are provided. These recommendations apply these integrated digital technologies to training directed at managing information to maintain a common picture of the battlefield.

The conclusion section integrates the training and research methods recommended in this report, in concert with digital technologies, to help design and develop a digital training environment directed at pictorial communication. Conclusions stress that method integration in virtual simulation, in particular, might provide an environment that effectively synthesizes training and evaluation. Key training conclusions consider the identification of training requirements,

training development and delivery, and training analysis and feedback. Key evaluation conclusions consider machine, soldier, and soldier-machine performance.

The methods recommended in this report should help training and evaluation researchers improve soldier-computer interaction to pictorially communicate battlefield situations. Method implementation will require coordinated efforts between these researchers and the developers of training, training simulation, and C⁴I systems to achieve the Army's information age objectives, such as a common picture of the battlefield.

BACKGROUND

Advances in digital information technology have affected job performance far more than job training (Army Science Board, 1995; Baker & O'Neil, 1994). Training lags are a paradox typical of technical advances intended to ease our life and work, that unintentionally add complexity, difficulty, and frustration (Norman, 1988). Progression in an information age may require applying the training capability of information technology to realize advances and overcome unintended consequences. This report's focus on how to apply digital training technologies to computer-mediated work assumes that many of the required answers reside in the problem: "Computers not only create training problems, but can be used to solve them" (Patrick, 1992, p. 435).

Computer-mediated work changes the underlying skills, abilities, and knowledge required to do the job (Craig, 1996). While many industrial-age jobs required repetitive performance of simpler procedural tasks in highly structured domains, information-age technologies often shift job requirements to more complex and uncertain environments that require information processing and decision-making skills. Particularly in their early stage, information technologies may increase requirements on a worker's knowledge, memory, and attention, and raise overall workload (Cook & Woods, 1996).

Advances in computers and the information they provide may also redefine a worker's job domain. On the one hand, by automating many aspects of job performance, information technologies may consolidate multiple jobs into an integrated computer-based workstation. On the other, by increasing information quantity and precision, information technologies may accentuate task differentiation and fragment a job domain into subspecialties (Cook & Woods, 1996). The ongoing redefinition of work from task-based products to team-based processes conflicts with the notion of "the job" as a fixed bundle of tasks (Cascio, 1995).

In the military, the impact of information technologies on job performance and training is of particular concern. The U.S. Army is focused on information-age warfare and the exploitation of information technologies to maintain a dominant force. At a visionary level, this is a force of cyber warriors with humans and computers allied as a joint cognitive system (Cook & Woods, 1996). Wary of change when the cost of errors may be critical, the military is proactively attempting to identify the training requirements and the unintended consequences of information technologies (Alberts, 1996). These changes not only affect job performance and training at individual and

collective levels, but the relationships among organizations and workers, such as commanders and their subordinates, and even the nature of military operations.

Investments in information technology underscore the need to leverage computers to improve their training and use. Given the complexity and pace of contemporary work, advanced information technologies may actually be essential for providing training and support technologies for computer-based work (Fletcher, 1995). For some time, trainers have realized that computers afford unique solutions to many important training problems (Seltzer, 1971). These solutions include providing alternative representations of information, adaptive control of training delivery, and instantaneous feedback to the responses of trainees. In particular, "a computer is virtually the only means of driving a complex dynamic simulation" of the work environment to provide a meaningful context for training (Patrick, 1992, p. 457).

In a word, our progressive alliance with and reliance on digital information technologies may be irrevocable (Negroponte, 1995). In response, researchers and practitioners are redefining training theory and design, and the very nature of the training environment. Computer-mediated work is blurring the distinction between training and job environments. Electronic Performance Support Systems (EPSS), for example, provide on-the-job assistance to computer-based workers (Cascio, 1995). Embedded training systems built into the worker's tools or equipment, such as a tank, exemplify how training is becoming part of the real world (Morrison & Orlansky, 1997; Witmer, 1996). Meanwhile, the ability of computers to simulate a worker's operational setting is bringing the real world to the training environment. The progressive fusion of the job and training environment induced by computer-mediated work poses opportunities and challenges in computer-based training.

Training is key to achieving the potential of digital technology to provide a meaningful portrayal of the job context, such as a battlefield situation. Training is also key to avoiding technology pitfalls. For example, a fundamental training issue is the technical paradox that networked computers may extend a worker's information requirements to literally global proportion but provide only a window-size interface for viewing and using that information. The intuitive appeal, or face validity, of graphic displays represents another technology pitfall: the better the display, the greater the risk that it will lead to misperception (Fadden, Braune, & Wiedemann, 1993).

Cook and Woods (1996) provide real-world documentation on how the introduction of integrated information systems often causes serious problems. They analyzed expert performance in an operating room after it was equipped with an integrated display that was designed to replace a suite of stand-alone patient monitoring systems. Their analysis disclosed numerous limitations, particularly during high-tempo work periods. They concluded that displays designed to provide more precise or transformed data representations often mask more meaningful data, from an expert user's perspective. They cautioned that integrated displays designed with a myriad of reconfiguration options are sometimes "as unwieldy as a pocket-knife with 50 tools" (p. 612).

This report draws upon available literature to apply digital technologies to training issues and methods for the Army's digital tactical displays. The intended consequence is to improve

training directed at the pictorial communication of the battlefield situation on digital tactical displays. A related concern is to avoid unintended consequences that might imperil soldiers using tactical displays on the digital battlefield.

The Digital Battlefield

The U.S. Army is embarked on a force modernization plan called "Joint Venture" that presumes future force dominance depends on advanced information technologies (Department of the Army [DA], 1995). Information is power, and a precept of the ongoing revolution in land warfare is that information is essential to combat power (Franks, 1994). A key objective directing this modernization effort is the need to establish deliberate patterns of future force operations: (a) project the force, (b) protect the force, (c) gain information dominance, (d) shape the battlespace, (e) operate decisively, and (f) sustain the force (DA, 1996a). Advanced information technologies must help establish these patterns on the digital battlefield of the future.

The concept of the digital battlefield is based on the provision of networked digital information systems to all soldiers in the areas of combat, combat support, and combat service support (Decker, 1996). These digital systems, referred to in this report as Command, Control, Communication, Computer and Intelligence (C⁴I) Systems, will serve as the "tools" required to perform the command and control functions directed at mission accomplishment. Command and control functions and tools, whether voice-based or digital systems, have no intrinsic value but that which is derived from mission success (Alberts, 1996).

In sum, digital C⁴I systems are expected to increase the quality and quantity of data available and assist commanders and subordinates by processing that data into more meaningful information. Digitizing the battlefield is defined as: the application of technology to acquire, exchange, and employ timely information horizontally and vertically integrated to create a common picture of the battlefield from soldier to commander (DA, 1998a, p. 5).

The Common Picture: A Focus on Pictorial Communication

The predicated military capability of digital information systems is often heuristically characterized as the ability to portray a common and relevant picture of the battlefield situation to all force combatants and supporters (DA, 1995). This "common picture" capability, as it will be referred to in this report, stresses the Army's expectation that digital systems will do more than provide needed information. The expectation is that these systems will transform data and information to pictorially depict meaningful battlefield situations on each user's C⁴I display. A recurrent and telling expectation is that this digital system interface will convey the user's battlefield situation "at a glance" (Bateman, 1997, p. 49).

As a concept, the common picture provides a meaningful and efficient summation of a complex objective, a communicative power akin to the "same sheet of music" expression. To achieve its full power, however, the concept must become a reality. At present, the concept of the common picture is not fully defined in an operational manner. Conceptual uncertainties are best

resolved in physical manifestation, such as notes on a page or graphical features on a tactical display. An operational definition of the common picture should specify the pictorial elements required on a C⁴I display to depict a meaningful battlefield situation. Notably, the elements depicted must be relevant to the user of that display or the user's duty position, and the picture must reflect meaningful changes on a dynamic battlefield.

As a construct, the common picture should provide an empirically verifiable account of the pictorial elements required for this picture product. Once the elements are defined, the construct should define an empirically verifiable process to create and maintain this picture product. This process would include both individual soldier and computer inputs to the product. Moreover, this process would include collaborative soldier and computer inputs across all the combatant and supporter participants in the battlefield situation.

Research and training methods are needed, however, to achieve the Army's common picture objective. Research methods should provide an empirically verifiable account of the pictorial elements required for this picture product and, the process by which those elements are created and maintained. Training methods should then address the identified process and product requirements, and ensure the pictorial elements depicted on a C⁴I display communicate information in a manner that can be understood and acted on.

Digital Technologies and Army Training

The Army's Joint Venture effort to leverage digital technologies includes both force and training development programs (DA, 1996a). Force development efforts for digital systems are central to Joint Venture. The impact of digital technologies on Army training is a much broader issue that impacts the basic pillars of Army training--the institution, the unit and self-development. The anticipated capabilities of digital technologies to deliver computer-based training directly to the trainee is shifting the Army's training strategy from balanced pillars to an emphasis on self-development and learner-controlled training (Hartzog & Canedy, 1997). Digital information networks foster this shift: "...the net will move more of the focus of education from the institution to the individual" (Gates, 1996, p. 217). A major impetus for this shift is the anticipated potential of digital technologies to provide distance learning and create a virtual classroom without walls (Army Science Board, 1995). There is a growing assumption in the Army that digital technologies can deliver training to any individual at any location.

A related assumption is that digital technologies can situate or "place" any trainee in any simulated work context, such as a battlefield situation. Future Army training will be based on an iterative sequence and mix of warfighting simulations--constructive, virtual, and live--in which soldiers and units conduct realistic tactical operations. These three types of simulations vary primarily with respect to their realism. Constructive simulation relies on simulated operators, equipment, and situations; virtual simulation, on real operators in simulated equipment and simulated situations; and live simulation, on real operators and real equipment in simulated situations (Sikora & Coose, 1995). Any combination of these three levels can be interactively linked to synthesize a training environment (Cosby, 1995). This report stresses the use of virtual simulation, a relatively powerful digital technology for Army training (Fletcher, 1994).

The Army faces a difficult challenge in its efforts to develop a digital training environment that capitalizes on digital technologies such as distance learning and networked simulation. Critics suggest the Army has not fully leveraged these capabilities and that training remains costly and simulations remain sub-optimal (Army Science Board, 1995). Others are concerned that such technological changes will make current training support systems obsolete and result in significant training deficiencies (U.S. Army Training Support Center, 1996). However, the Army was a forerunner in the development of distance learning and distributed interactive simulation technologies. Despite dwindling resources and the complexity of the training problem, the Army is actively committed to using these technologies to improve training (Hartzog & Canedy, 1996). A notable example of this commitment is the Advanced Warfighting Experiments (AWE) conducted by the Army to learn about the digital battlefield.

The Common Picture: Key Lessons Learned from the AWEs

The Army's ongoing Joint Venture effort is providing valuable lessons and identifying key research and development issues directly related to the common picture objective. The AWE called Focused Dispatch formally codified the issue "What is the process of maintaining the common picture?" at the battalion/task force level (U.S. Army Armor Center, 1996). The answer, unfortunately, was "swivel-chair integration." Staff personnel manually re-entered digital reports and messages between noninteroperable C⁴I workstations. With no tactical display to integrate digital communications, tactical operations center (TOC) staff members had to glean essential information from each display and also transfer the information manually to a common situation display, an acetated mapboard. This AWE's concern with the common picture also underscored the need for a systematic analysis of the informational elements required to depict the common picture (Lickteig, 1996).

For a subsequent AWE, Task Force (TF) XXI, TOC personnel and individual vehicle operators were provided a more interoperable suite of digital C⁴I systems. In addition, some of the key C⁴I systems provided various filters that allowed the users to customize their display. Filter types included the ability to select a desired rate for updating vehicle locations, and "battlespace" filters that restricted communications received to a user-specified area of interest. As operators began to learn how to use these filters, the issue of what information was relevant to a common picture quickly emerged (R. Munden, personal communication, November 23, 1996). For depictions of the enemy situation, for example, company commanders and their subordinates required information at the individual vehicle level. Higher commanders, such as the brigade commander, required a depiction of enemy information that aggregated individual vehicles into unit-size icons. A key research question raised was "how to provide enemy information relevant at each operator level without cluttering the tactical display."

Many of the lessons learned from the TF XXI AWE concentrate on the training requirement to help warfighters better understand the battlefield situations depicted on their tactical displays. The Commander of the U.S. Training and Doctrine Command (TRADOC) concluded this AWE underscored that "Leadership training should be changed to help commanders adapt to and trust the rapid computerized representations of the battlefield" (Hartzog, 1997, p.7). In support of that requirement, for example, the U.S. Army Intelligence Center proposed a Master Analyst Program

for the All-Source Analysis System (Turner, 1997). This program is designed to provide commanders specially trained intelligence analysts who can apply and integrate digital intelligence systems and products into the mission.

Such AWE lessons learned identify some of the key training research issues that should be addressed for the Army's digital tactical displays to achieve the common picture objective, the pictorial communication of the battlefield situation.

Learning Theory and Instructional Design

If digital technologies are not being leveraged for training and instruction, why not? What barriers deter the development and application of training technologies? Some identified barriers to technology use in training include: the entrenched structure of training and educational systems; the short-sighted concern of technology developers; and a project, rather than program, focus in research and development (Baker & O'Neil, 1994). Other barriers identified by Patrick (1992) point more directly to training theory and design. These barriers include simplistic assumptions about knowledge, and an emphasis on content rather than presentation formats and medium characteristics. Patrick also emphasizes the lack of state-of-the-art training principles and poor dialogue between science and practice. Perhaps the greatest barriers to the use of digital technologies for training are identified in the following statement: "...the bottleneck remains the same: a lack of expertise in how to create good training programs, coupled with the fact that any training development is still a labor-intensive activity" (Patrick, 1992, p. 456).

The barriers identified to the effective use of digital technologies in training are substantial. Their overall magnitude should temper expectations for immediate and immense training improvements from technical training solutions. However, this report attempts to breach two of these barriers, in particular. First, the methods recommended represent a programmatic approach to the application of digital technologies for training. Second, these methods strive to improve training format by exploiting the medium characteristics unique to digital technologies for pictorial communication.

Army Training Theory and Design

Army training is traditionally based on Instructional Systems Development (ISD) procedures adapted from a systems approach to training analysis, design, and evaluation. The ISD model guides the systematic analysis of the information to be learned and the tasks to be performed and imposes an external structure for step-by-step sequenced delivery (Konoske & Ellis, 1986). This analysis provides a coherent framework for designing training content based on prerequisite requirements. Behavioral learning theory complements ISD evaluation by decomposing complicated tasks into a series of measurable behaviors at the task and subtask level and consolidating observable "outputs" into training outcomes.

The ISD paradigm for training reflects its industrial age origins with an emphasis on standardized, mass production of trainees. The standardized procedures of ISD are geared to the simultaneous training of multiple trainees on the same training content in the same amount of time.

Typically, class and course structures define the traditional educational system and mimic the physical production efficiencies of the industrial revolution. Observable performance measures enable normative standards for assessing training proficiency with respect to institutional, but not necessarily individual, training objectives. Standardized outcome data support the sorting, versus learning, of trainees for subsequent placement or fill (Reigeluth, 1996).

The behavioral theory underlying traditional education and training stresses a presentation and response paradigm that regards the trainee as a passive recipient of the content delivered. Content is viewed as an external, physical reality to which course delivery conditions appropriate trainee response. Training design employs rote and repetitive learning procedures for pairing task conditions with task performance. "Classes" of trainees are viewed as equally responsive to a course treatment that results in equal proficiency (Osin & Lesgold, 1996).

Contemporary Learning Theory and Design

For over three decades, more contemporary learning theory and design approaches have challenged the objectivist foundation of behavioral learning theory and production-oriented ISD principles (Driskell, Olsen, Hays, & Mullen, 1995). Three of the primary challengers are cognitive, constructive, and situated learning theorists. While these theories are only briefly discussed here, military trainers might appreciate the learning theory analysis of traditional and contemporary (but not situated) learning theory provided by Driskell et al. (1995). That analysis compares learning theories with respect to how learning occurs, factors influencing learning, role of memory, how transfer occurs, types of learning supported, and the structure of training. For a more detailed account of situated learning theory, Druckman and Bjork's (1994) review of training transfer is recommended.

The emergence of cognitive psychology contested more traditional learning theory and design by focusing on mental rather than physical representations of systems and processes. Typically, ISD ignores the trainee's cognitive framework, including prior knowledge and mental representation of the task situation. In contrast, cognitive theory addresses how the mind structures and processes information acquisition, storage, integration, and retrieval functions. The application of cognitive learning theory to instructional design stresses the match between what learners already know and training content (Konoske & Ellis, 1986). Cognitive analyses and knowledge elicitation methods enable the development of mental models to bridge this training gap.

Constructive and situated learning theories assert the need for training designs that make training content more personally meaningful to each trainee. Constructive theorists stress that meaning and knowledge exist only in the mind and must be actively constructed by each trainee (Jonassen, 1991). Situated learning theorists emphasize that critical task and environmental features and cues required for meaningful training are only available in the actual job situation (Lave & Wenger, 1991). The two theories converge, to some degree, on the point that training should occur in job settings that represent the unique and dynamic situations that typify real world job situations and challenges.

Theoretical Implications for Digital Training

To derive digital training implications for pictorial communication, some key theoretical aspects of contemporary learning theory are reviewed. This review begins by considering the emerging role of the worker's mental model and its external complement, the microworld model. Then, the role that perceptual processes play in linking and matching these models is considered.

The Worker's Mental Model

Contemporary learning theories stress that the cognitive aspects of the trainee, such as prior knowledge and mental representations, should be matched to an overarching structure of the task material to be trained (e.g., Driskell et al., 1995). A cognitive training focus goes beyond linear explanations about *what* to do, by also addressing the *how*, *why*, *when* and *where* explanations for required job performance. These additional explanations provide the worker a basis for developing or adapting a mental model of the external job environment. Mental models are essentially internal representations of external systems. Mental models may entail: descriptions of system purpose and form; explanations of system functions and observed system states; and predictions or expectations of future system states (Fletcher, 1994).

Cognitive training principles stress the importance of mental models in all phases of skill acquisition--controlled, associative, and automatic--and for both part- and whole-task training. During the initial phases of training, trainees should be provided a simple overview of the system that epitomizes, versus summarizes, the total system (Reigeluth, Merrill, Wilson, & Spiller, 1980). As new procedures are learned, they should be related to the framework of that mental model. An adequate mental model is expected to provide a coherent reference that aids the recall and application of task information. By linking trained tasks and subtasks to a model of the job, that knowledge is more likely to be usable or available when it is required later, on the job.

The collaborative nature of teamwork extends training concerns to the issue of a shared mental model among workers. Shared mental models may be required to enhance a team's coordination of job requirements and improve overall team performance. For general training implications related to shared mental models see Salas, Prince, Baker, & Shrestha (1995).

A more comprehensive notion of a mental model goes beyond system states or situations to include the dynamic processes underlying changes or transitions between states and situations. In this sense, a mental model is composed of a connected runnable set of objects, or mental entities (Williams, Hollan, & Stevens, 1983). A runnable mental model, for example, might afford projections of a future battlefield situation based on the current situation. Workers may use their mental model to identify solutions to work problems by changing a parameter they believe defines a state in order to achieve a different state representation. Transitions between states or situations may be the most important aspect in the development of a mental model (Kozma, 1991).

Microworld Work Models

"Model" is an imprecise term with numerous meanings, as discussed by Swezey and Llaneras (1997). In particular, their discussion of this ambiguity notes that simulation and modeling are often used interchangeably and that a simulation model is usually a computer-based representation of a dynamic process. They also suggest that training-oriented models should have several unique characteristics: reliable representation of a real situation, control over represented characteristics, and deliberate omission of certain situational characteristics.

This report's integrated concept of microworld models and the worker's mental model is guided particularly by the writings of Kozma (1991, 1994). Kozma asserts that learning with media is a complementary process in which representations are constructed and procedures performed. His work suggests that digital media such as microworld models create a unique training environment that supports information exchanges and interactions between coprocessors, the trainee and the computer. The links between these joint cognitive systems during training should mirror their links on the job.

The advantages and varieties of training-oriented models, and computer models in particular, are ably documented (Laughery & Corker, 1997; Swezey & Llaneras, 1997). This work provides numerous examples of methods for applying computer-based models to a wide range of training domains. This discussion is restricted to two microworld models directly related to this report's training concerns.

First, a model for a man-machine integrated design and analysis system (MIDAS) was developed as a predictive model of human performance to aid air crew system designers (Laughery & Corker, 1997). Although MIDAS was not designed as a training model, it was intended to study the *differing* information requirements and behaviors, including communications, of various types of workers in the same job situation. In order to predict the collaborative performance of flight crews and air traffic controllers, MIDAS includes an "updatable world representation" and a closed-loop communications model. As a predictive design model, method applications have focused on comparisons between the model and actual crew and controller performance.

Second, a team model training (TMT) methodology by Duncan et al. (1996) was developed to train Information Center Anti-Air Warfare teams on Navy ships. The model's design for team training provides several methods of direct relevance to training individuals and small groups engaged in collaborative work. In particular, TMT includes a model of team performance and communications designed as an open-loop model. Applications of the TMT model, therefore, both passively and interactively train team members. Communications modeled by TMT, however, are predominantly verbal. In contrast, a model based on digital communications between C⁴I systems and their displays may provide a training medium that more directly reflects the job setting. With respect to training analysis and feedback, TMT performance assessments were predominantly based on experts' direct observation and post hoc review of videotapes.

Perceptual Focus: Matching Internal and External Models

One theme re-emerging from more contemporary learning theories is the pivotal role of perception, especially the visual channel, in task learning and performance. Early learning theory grappled with the issue of what constitutes or represents "identical elements" between different task situations (Thorndike & Woodworth, 1901). Nearly a century later, cognitive theorists contend the identical elements theory remains viable but the focus has shifted from external observables to internal representations or mental pictures of those elements (Singley & Anderson, 1989).

This renewed perceptual focus in training and performance tracks from part-task training on feature and pattern recognition (Fischer & Geiwitz, 1996) to whole-task training such as situational recognition in complex, decision-making job environments (Klein, 1989). The goal of turning novices into experts has directed the attention of training developers to a cognitive analysis of how experts differentially use their skills to solve job-based problems. A growing consensus about experts is that their solutions are based on salient perceptual cues in the problem situation, and that expertise entails automated subskills such as pattern recognition that support more controlled skill-based solutions and decisions (Fisk & Rogers, 1992).

At the part-task or subtask level, Fischer & Geiwitz (1996) provide a cognitively-based approach for training pattern recognition that addresses both the perceptual aspects and meaning of patterns. While their training approach acknowledged the crucial role of practice and feedback for developing pattern recognition skills, it was paper-based. Digital training technologies provide a unique training solution for the drill and practice required to develop more automated processing skills, such as pattern recognition (Salisbury, 1990). More automated map reading skills result in faster reaction time, less variability, and less susceptibility to information overload (Fisk & Eboch, 1989).

At the task level, a unique training solution that digital technologies might bring to pictorial communication, centers on the meaningful representation of the job context. Information systems that portray a rich and complex context can be an effective support for natural decision-making (Klein, 1989). A tactical display can provide a direct perception of such a context, the battlefield situation, if its representation is appropriate both for acting on that environment and for thinking about the environment at the level the user chooses (Rasmussen & Pejtersen, 1995).

The tactical display and its controls should perceptually reflect the task and subtask structure of a user's hierarchical perception of task requirements. The key to understanding mastery of a complex task, such as chess or tactical decision-making, is in the immediate perceptual processes where the task is structured (Rasmussen & Pejtersen, 1995).

Practical Implications for Digital Training

Training theory directed at training effectiveness must be balanced by consideration of training efficiencies. A concern common to practitioners and theorists is the need to customize, versus standardize, approaches to training (Reigeluth, 1996). The shift from behavioral and ISD-based training standardization started with programmed learning in the 40's (Patrick, 1992). The

shift was energized by the emphasis of cognitive learning theory on relating internal and external representations. Cognitive analyses of how the mind structures and processes information have ranged from categorical differences between novice, intermediate, and expert performance to individual differences.

Moreover, many contemporary theorists endorse a form of apprenticeship or mentoring which tends to immerse trainees in authentic job situations. Real or highly representative job situations provide trainees with more complete and natural feedback on their performance, such as resultant changes, and corrective feedback to eliminate errors and misconceptions (Montague & Wulfeck, 1984). While the emerging requirement to customize training and provide realistic job settings may increase training effectiveness, it will increase the complexity and cost of training (Driskell et al., 1995).

The effectiveness of customized, or individualized, training is well documented (Regian & Shute, 1992). With a personal instructor, individuals may exceed the achievements from group-based instruction by two standard deviations, achieving 98th percentile rankings (Bloom, 1984). The cost of manually customizing training, however, is increasingly prohibitive, particularly for the military (Fletcher, 1995). The cumulative effects of training inefficiencies are sizable when you train 200,000 individuals per day (Seidel & Perez, 1994), and that estimate includes only the institutional (school house) pillar of military training, not self-development and unit training.

Additional costs associated with the assessment, versus the delivery, of training and performance further disparage a reliance on manual methods. Efforts to increase the reliability of manual methods for assessing performance may cost three times more than the less reliable methods routinely used in education and training (Stecher & Klein, 1997). Such monetary estimates do not include the learning costs incurred with manual assessment procedures that limit and delay training feedback, analysis, and evaluation. Nor do they include the operational costs for military training on actual weapon systems, 1-3 orders of magnitude more than simulation-based training alternatives (Fletcher, 1995).

The alleged potential of digital training technologies, however, awaits confirmation. In a critical analysis of emerging instructional technologies, Hooper and Hannafin (1991) state that unique causal relationships between technology and learning are not conclusively established. They stress that neither instructional design nor learning may differ as a consequence of technology, in a fundamental manner. However, their analysis identifies how advanced technologies should and should not be applied to five cognitive phases fundamental to the design of instruction: retrieving, orienting, presenting, encoding, and sequencing. Moreover, they conclude: "...emerging instructional technologies undoubtedly possess the potential to deliver effective and efficient instruction previously impossible or at least impractical" (p. 91).

Contemporary learning theories converge in endorsing digital training technologies, we conclude. Although they diverge in many key aspects, they confront a common dilemma: the goal of training customized to individual and job differences is too costly with manual training technologies. Advocates of digital training technologies assert that computers can provide the most *personalized* instruction (Regian & Shute, 1992). They propose that a computer's almost unlimited

capacity for information, including information about the trainee, may make it more aware of and responsive to the individual needs of each trainee than humanly possible. Winn (1989) states this position:

...the only viable way to make decisions about instructional strategies that meshes with cognitive theory is to do so during instruction using a system that is in constant dialogue with the student and is capable of continuously updating information about student's progress, attitude, expectations, and so on. (pp. 39-41)

Expectations of the computer as a personalized tutor, master, or mentor seem premature (Driskell et al., 1995). A more somber assessment of the barriers that must be overcome before the computer can serve as an effective tutor for real-world, and often inherently complex, job domains was provided by Patrick (1992, p. 472): "the enormity of this task is beyond our current capabilities."

Background Summary

The background section considered the profound impact of advanced information systems on job performance and training in commercial and military organizations. Despite the negative impacts such systems often have on job performance, barriers that contribute to a lag in training applications persist. Reasons for training lags and negative impacts were reviewed with special emphasis on reasons related to inadequate methods for training and evaluating computer-mediated work.

The review of the Army's requirement for training and evaluation methods directed at the digital battlefield of the future focused on the Army's expectation that C⁴I systems should provide warfighters and supporters a common picture of the battlefield. The report's emphasis on pictorial communication stressed the Army's expectation that C⁴I systems should literally depict a picture of the battlefield that communicates needed battlefield information in picture formats the user can satisfactorily receive, understand, and act on. Research methods are needed to define the common picture and training methods are needed to achieve it.

The remainder of this background section attempted to identify research issues and methods pertinent to the application of digital technologies to train pictorial communication. This review stressed the ability of digital information systems to match training content to what trainees already know by emulating microworld work models, such as a battlefield situation depicted on a C⁴I display, and the mental models of trainees and users. Digital training methods to perceptually link these models were considered for training pictorial communication. Finally, some practical implications of digital training were examined in order to balance training efficiency and effectiveness.

As indicated, the intent of this background section was to identify documented methods that could apply advanced information systems to training and evaluation efforts directed at the pictorial

communication of battlefield situations. The subsequent method section will attempt to capitalize on these documented methods. The method section provides a relatively integrated set of method recommendations designed to help the Army meet some important C⁴I training and evaluation requirements, and particularly the common picture objective.

METHOD

This section presents an integrated set of research and training method recommendations directed at the pictorial communication of battlefield situations on C⁴I displays. These method recommendations are organized into three main areas of research that should help achieve the common picture objective: define, communicate, and maintain a common picture of the battlefield. For each of these three areas, research issues are identified and a corresponding set of method recommendations is provided to help address the issues raised. Table 1 provides an overview of the research areas, issues, and method recommendations addressed in this report.

The method recommendations are based, in large part, on methods selected from the literature reviewed. Discussion, therefore, describes the recommended methods in some detail, or directs the reader to others' documented descriptions. The Table 1 method recommendations consolidate and adapt a relatively integrated set of training and evaluation methods to more directly address the research issues identified in this report. These method recommendations capitalize on the relatively unique capability of digital information systems, as reviewed in the background section, to synthesize training and evaluation. Overall, method recommendations will stress the computer's ability to create pictorial and interactive formats for training and feedback, and to empirically assess performance

Define the Common Picture

This section raises some key research issues that should be addressed to define the common picture requirement and translate this concept into an empirical and useful construct. Initially, conceptual and operational definitions of the common picture must be developed to provide a basis for realizing this Army objective. Corresponding method recommendations begin with a working definition of the common picture based on relevant aspects of METT-T. A rationale for this definition is provided based on Army training and doctrine, and its concurrence with current and future system C⁴I requirements is addressed. Recommended methods for developing an operational definition stress the need to first scope the problem. Problem bounding methods focus on the information requirements for structured battalion or brigade exercises at duty position level, matched against the information capabilities for a battalion or brigade level C⁴I system.

Table 1

Overview of Research Areas, Issues, and Method Recommendations

Areas	Issues	Method Recommendations
Define the Common Picture	Develop a Conceptual Definition Develop an Operational Definition Identify Operational Context Identify Operational C ⁴ I System Identify the User Level Determine Information Requirements Assess C ⁴ I Information Capabilities Assess Performance, Give Feedback	Relevant METT-T on C ⁴ I Display Bound the Definitional Problem FXXITP Exercises FBCB ² Duty Position Knowledge Elicitation Expert Process Tracing C ⁴ I Display Codes Instrument C ⁴ I Systems
Communicate the Common Picture	Shape C ⁴ I Representations Shape Mental Models Pattern Recognition Situation Recognition	C ⁴ I Display Decodes Alternative Format Comparisons Individual Training Automatic Processing Pattern Transformation Automatic Processing Situation Transformation Stimulus Reduction Animation Perceptual Augmentation Time Compression and Expansion
Maintain the Common Picture	Develop Communications Model Integrate Digital Technologies Develop Multi-Level Training	Common Picture Communications Model Expert and Machine Versions Link Simulations, C ⁴ I Systems and CPCM Constructive Virtual Live Individual Training Observer and Performer Mode Small Group Training Collective Training Pre and Post Exercise

Note. METT-T = Mission, Enemy, Terrain, Troops, and Time; FXXTP = Force XXI Training Program; C⁴I = Command, Control, Communications, Computers and Intelligence; CPCM = Common Picture Communications Model; and, FBCB² = Force XXI Battle Command—Brigade and Below.

Once the definitional problem is scoped to a more workable size, the issue of determining user information requirements is addressed. To identify user information requirements, methods for eliciting user and expert knowledge in commercial and military settings are briefly reviewed. This review provides a basis for selecting and adapting the methods recommended for further defining the common picture requirement. Alternative methods are recommended to address more pragmatic and thorough knowledge elicitation requirements. This report's primary recommendation, however, is a form of process tracing that elicits experts' knowledge during actual exercises. Once information requirements are determined, the issue of assessing C⁴I capabilities against those requirements is raised. An evaluation method is recommended to address this issue that focuses directly on the pictorial information provided by a C⁴I display.

Finally, this section raises the need for instrumented C⁴I systems that provide a log of human-computer interaction. Discussion of this issue underscores the need for automated analysis and feedback on the information tasks that are a basis of command and control performance. Corresponding method recommendations describe how instrumented C⁴I systems can automatically analyze the collaborative process required to develop the common picture across a unit and, the common picture product depicted on users' C⁴I displays at any point during a unit's training exercise. A working example of such methods is described called automated pictorial comparisons, based on normative or criterion standards of a common picture.

Develop a Conceptual Definition: A METT-T Approach

The C⁴I display and interface is a primary point, or means, of interaction between the soldier and the battlefield situation. The display's representations should enable actions and thought on the depicted environment, at the level the user chooses (Rasmussen & Pejtersen, 1995). Methods for defining the common picture, therefore, should originate with the user's mental picture of a battlefield situation.

Key factors comprising a battlefield situation are traditionally and heuristically identified as METT-T. For many years, METT-T has provided a coherent training structure for essential types of battlefield information: who, what, where, how, when, and why. This METT-T organization of battlefield information remains central to current doctrinal concepts such as Battlefield Visualization and Battle Command. For example, guidelines for staff training state "the major components of commander's visualization are based on METT-T factors" (DA, 1997b, p. I-1).

More specific subsets of information requirements, such as commander's critical information requirements (CCIR), reflect a similar organization. "The commander must review his critical information requirements for each operation based on METT-T factors" (DA, 1997b, p. I-2). Notably, the three types of CCIR are also METT-T based: priority information requirements (PIR) relate to enemy and terrain; friendly forces information requirements (FFIR) relate to the combat capabilities of own and adjacent units or troops; and, essential elements of friendly information (EEFI) relate to protecting troops from the enemy's information gathering systems (DA, 1996c). Across all three types, critical information is that information that directly affects the successful execution of operations.

The METT-T organization of battlefield information also concurs with the Army's overall approach to C⁴I system design and assessment. "The Army Battle Command System (ABCS) must provide the flexibility to tailor and access the ABCS common database to meet a specific set of critical information needs as defined by METT-TC"¹ (DA, 1998b, p. 15). The ABCS requirement for a METT-T based approach is clear and compelling: this capstone system defines the requirements for *all current and future* Army C⁴I systems.

Defining the domain and content of user information requirements is an essential issue to improving training and evaluation methods for C⁴I-based operations. Admittedly, other informational structures or frameworks than METT-T might be used to define the information requirements for C⁴I displays, to include tasks, functions, or battlefield operating systems. Strategies to restrict the domain of requirements might also prove useful. Such strategies might target the information required for selected processes, products, or outcomes related to unit performance; or address a subset of information requirements, such as CCIR. While future research efforts might carefully consider the tradeoffs associated with alternative informational domain structures, this report's methods will use the METT-T approach for defining and assessing user information requirements for battlefield depictions on C⁴I displays.

A Working Conceptual Definition of the Common Picture

For this report, a common picture of the battlefield is defined as the relevant METT-T information pictorially communicated by a C⁴I display. More detailed discussion of this definition is provided in the following section that addresses developing an operational definition of the common picture. Three aspects of this definition are noted. First the specification of METT-T battlefield factors reflects the Army's doctrine and training literature, and capstone requirement for C⁴I systems, as previously discussed. Second, this definition's focus on pictorial formats underscores the assumption that a C⁴I display should literally portray a visual image of the situational elements that comprise a battlefield situation. Third, the emphasis on communication stresses the role of a C⁴I display in promoting an understanding of the battlefield situation, a role reinforced through METT-T structure and pictorial formats.

Develop an Operational Definition: Bound the Problem

To provide an empirical basis for training and assessing performance, the common picture concept must be operationally defined. An operational definition of the common picture should specify what pictorial elements are required on a C⁴I display to depict a meaningful battlefield situation, and the process by which those elements are generated. At a conceptual level this may seem fairly easy, as indicated by recurrent assertions that a soldier needs to know the location of enemy and friendly units and self to have situational awareness. The working definition proposed herein for the common picture, however, entails a more comprehensive and challenging

¹ METT-TC is a recent extension of METT-T that adds a civilian (C) factor. Civilian considerations, however, are not yet reflected in most Army training and doctrine publications and they will require additional specification. This civilian factor is, therefore, not addressed in this report.

requirement. Clearly, this definition extends the requirement beyond Enemy and Friendly information, to include Mission, Terrain and Time factors.

Additionally, more detailed specification of the information related to each METT-T factor is also required. For example, soldiers generally need to know more about the enemy than its location. Elements of required information in an enemy Spot report format, for example, include: size, activity, location, unit type, time, and equipment (SALUTE). Additionally, soldiers may need to know what is the intent or disposition of an enemy unit and what are the enemy's capabilities. Table 2 provides some notional informational elements that soldiers might require for each METT-T factor. This list is provided as a working example of the informational detail that may be required to provide a meaningful picture of the battlefield situation.

Moreover, this report's conceptual definition stresses that required METT-T information should be pictorially communicated by a C⁴I display. The emphasis on pictorial formats raises the need to literally depict a picture of the battlefield situation on a C⁴I display. While textual and tabular formats may be needed for additional detail, a pictorial representation of the physical situation is the operational standard by which the common picture requirement should be assessed. The emphasis on a picture that communicates stresses that a C⁴I display should convey needed battlefield information in picture formats the user can satisfactorily receive, understand, and act on.

Research and training methods to establish an operational definition of the common picture are recommended and discussed throughout this section. The more immediate concern, however, is to scope or bound the definitional problem to a manageable level. Three key bounding issues are identified, and method recommendations for addressing these issues are provided. These recommendations bound the definitional problem by identifying an operational context, an operational C⁴I system, and an operator level, namely duty position. Alternative recommendations may certainly be warranted, such as a different operational context or a mix of different C⁴I systems. The current intent is merely to illustrate how the definitional problem might be bounded, and establish boundary examples that will be used in this report.

Identify an Operational Context

The operational context for the U. S. Army is changing and expanding as it becomes an information age force (DA, 1996a). Efforts to identify and define future operational contexts are an ongoing effort. The immediate concern, however, is to select an operational context that is both representative and relatively well defined to bound the definitional problem. At best, the operational definition of a common picture that emerges from the context identified here might provide a solid foundation for future training and evaluation efforts.

A key part of the Army's ongoing effort to improve training is the Force XXI Training Program (FXXITP). A basic goal of this program is to provide structured, simulation-based training exercises to improve force readiness. A forerunner of the FXXITP was the Virtual Training Program (VTP) developed by the Army Research Institute at Fort Knox using virtual and constructive simulations at Fort Knox (Campbell, Campbell, Sanders, Flynn, & Myers, 1995). The VTP methodology is rooted in a set of structured and tactically realistic scenarios.

Table 2

Notional METT-T Information Requirements

Mission	Enemy	Terrain	Troops	Time
WARNO	Location	Observation	Location	Plan
OPORD	Composition	Cover	Organization	War Game
OPS Overlay	Disposition	Concealment	Ability to See	Prepare
CDR's Intent	Ability to See	Obstacles	Ability to Move	Rehearse
COA	Ability to Move	Key Terrain	Ability to Shoot	Execute
FRAGO	Ability to Shoot	Approach Avenues	Ability to Communicate	Sync Execute
	Ability to Communicate	Weather	Ability to Sustain	
	Ability to Sustain			

Note: WARNO = Warning Order; OPORD = Operations Order; OPS = Operations; CDR's = Commander's; COA = Course of Action; FRAGO = Fragmentary Order; Sync = Synchronization

Central to the VTP's structure is the detailed specification of scenario factors such as the location, organization, status and disposition of friendly and enemy forces, and the delineation of scripted events during the exercise. The VTP scenarios are task-based and primarily address the execution phase of a mission. They also include planning phase stimulus materials, however, such as operations orders and overlays.

The VTP methodology was adopted, in large part, by the FXXITP. The original platoon to battalion scenarios were based on the National Training Center (NTC) and addressed three basic Armor and Mechanized Infantry missions: Defense in Sector, Movement to Contact, and Deliberate Attack. This operational context has been routinely tested and upgraded during expansion to brigade-level exercises (Campbell, Graves, Deter, & Quinkert, 1998). This expansion from battalion to brigade-level training exercises also recognized the need to address the planning, preparation, and execution phases of a mission. Additionally, the brigade training exercises include detailed vignettes tailored to the unique informational requirements of a wide range of combat and support duty positions. By design, the FXXITP exercises are tailored to the constraints and capabilities of virtual and constructive warfighting simulations.

The recommended operational context for defining the common picture on a C⁴I display, therefore, is the training exercises developed by the FXXITP. More specifically, this context includes battalion and brigade level training exercises that address three representative and relatively well defined missions: Area Defense, Movement to Contact, and Deliberate Attack. As noted, alternative context recommendations for different missions, locations, and organizations may be warranted to further identify information requirements for a common picture.

Identify an Operational C⁴I System

The current operational C⁴I systems of the U. S. Army represent an uneven mix of capability and compatibility, as noted in the background discussion of AWE lessons learned. Such lessons have resulted in a capstone requirement for a C⁴I system of systems called the Army Battle Command System, or ABCS. More specifically, the ABCS document encompasses seven major C⁴I systems and an unspecified number of legacy systems. The purpose of the ABCS requirement is to ensure common C⁴I system capabilities, including compatibility, that result in "a user defined relevant common operational picture of the battlefield (DA, 1998b, p. 4). Realistically, this capstone requirement document describes itself as a *living* requirements document.

Prior identification of a battalion and brigade operational context directs identification of an appropriate operational C⁴I system. A C⁴I system called Force XXI Battle Command--Brigade and Below (FBCB²) is one of the seven components of ABCS. The FBCB² system is the primary C⁴I system for digitally linking brigade and battalion echelons to soldier and platform level (U.S. Army Armor Center, 1997). The method recommendation, therefore, identifies FBCB² as the operational C⁴I system for determining the pictorial informational elements required for a common picture at brigade and battalion levels. The FBCB² system will serve as a working example to apply the methods recommended in this report.

Identify the Operator or User Level

Information relevance is an issue critical to the common picture concept and construct. However, the relevance of information is user dependent, particularly from a contemporary learning perspective. In the military, the relevance of information is directly linked to the user's duty position, such as the CCIR that focus on the commander's duty position. Every warfighter and supporter duty position has unique informational requirements.

Since different duty positions result in different information requirements, some have suggested that the term "common" picture may be a misnomer (R. Munden, personal communication, November 23, 1996). The authors do not concur: a force's duty positions and information requirements are shaped by a common job setting, the battlefield situation, and a common mission task. By analogy, the notes relevant to each musician depict their unique portion of the "same sheet of music." The relevant notes or symbols for each player are choreographed to a common score, a common battle.

This report, therefore, recommends methods for assessing informational relevance based on duty position. Alternative recommendations, not pursued in this report, include relevance by echelon² and individual. Ultimately, C⁴I displays may allow individuals to tailor the situation depicted to match their unique mental model. Filters or system settings that automatically gather relevant information and gate irrelevant information could allow individuals to tailor or customize

² For a more detailed discussion of viewpoint differences by military echelon see the U.S. General Accounting Office (1991).

a battlefield picture to their own area of interest, a user-defined battlespace. In an effort to bound the definitional problem, however, the more immediate issue pursued in this report is information relevance, by duty position, on a C⁴I display.

Additionally, the notion of relevance includes timeliness. Various definitions of the common picture have cited a requirement for real-time, or near-real-time, battlefield depictions. Military practice and terminology, such as latest time information of value (LTIOV), underscores the temporal aspect of informational relevance. To develop an operational definition of the common picture that includes timeliness, the currency of the information depicted on a C⁴I display, evaluation methods should explicitly address temporal requirements.

Only the users of a tool can adequately define the tool's requirements. Adequate standards for informational content and relevance, including timeliness, on a C⁴I display are needed to define the common picture requirement. Adequate research methods are needed to help users operationally determine their common picture information requirements.

Determine Information Requirements

This section begins with a review of research methods for determining information requirements called knowledge elicitation methods. The methods reviewed provide a basis for the method recommendations that immediately follow. These recommendations attempt to improve upon the methods reviewed, and adapt them to operationally define users' common picture requirements, as previously bounded. Method recommendations include both pragmatic and thorough approaches to knowledge elicitation. The concluding recommendation, however, is a more thorough method based on expert observation of the information required by duty position during conduct of structured training exercises.

Although the methods recommended rely on expert performers and observers, a cognitive analysis of users' information requirements should include both experts and novices. Display representations appropriate to the mental models of experts may be an operational objective for C⁴I systems. Such representations may also be needed to support more terminal training objectives. Initial training objectives, however, should require that instructional content relates to novices' mental models.

If the goal of a C⁴I display is to construct an external reality consistent with the mental constructs of the user, research tools are required to elicit and make explicit the worker's mental model, the relevant knowledge base of the user. As noted, an ISD-based analysis of training content or tasks addresses the external structure of information independent of its internal representation. In contrast, a cognitive analysis should help identify the relevant data elements and informational patterns of a user, and how these patterns relate to external structures and performance requirements (Cooke, 1994).

For a thorough review and analysis of knowledge elicitation methods see Cooke (1994). Cooke's review summarizes the dimensions and tradeoffs associated with three families of knowledge elicitation techniques: observations and interviews; process tracing, such as protocol

records during task performance; and conceptual techniques directed, for example, at defining, analyzing, and interpreting the structure of a knowledge domain. Cooke's review also provides general recommendations about the types of techniques applicable to different knowledge documentation goals.

Pertinent examples of knowledge elicitation methods used to identify the informational elements and battlefield patterns of military experts during mission planning, are provided by Fischer & Geiwitz (1996). Initially, an Information Needs Analysis (INA) method was used to elicit general battlefield patterns. The INA method assumed the required information was in the standard stimulus materials provided, such as operations orders and plans, for the mission planning phase. Experts were interviewed to identify the battlefield patterns they detected in the stimulus materials. Next, sorting methods required other experts to classify operational orders and 78 different battlefield elements, such as mission, resources, task organization, and enemy intentions, into meaningful categories. Finally, interview and protocol analysis methods were used to elicit 40 different terrain patterns with military significance.

Related examples of knowledge elicitation methods are research on similar battlefield situations and the metacognitive skills for battlefield situation assessment by Federico (1995; 1997). Both of these efforts employed similar stimulus materials in which Navy participants' knowledge of the stimulus situations was initially elicited by card-sorting the situations into discrete clusters and then labeling the clusters. The work on similar situations addressed expert versus novice knowledge bases by requiring participants to weigh the importance of informational elements on the situation, their source, and their similarity (Federico, 1995). The work on metacognitive skills for situation assessment addressed how the mental models of military personnel affect their perception of, and decision-making on, battlefield situations (Federico, 1997).

In addition to card-sorting and labeling, other knowledge elicitation methods used by Federico (1997) included pair-wise similarity ratings of stimulus situations (1-7 point rating scales), and participants' representations of their process models for tactical decision-making. Participants illustrated their own model for decision-making by spatially arranging its cognitive components, to include: enemy information, scenario event sequence, participant's formal training on doctrine and tactics, participant's experience and observations in military exercises, situation assessment, similarity recognition, and tactical action. Elicitation methods required participants to weigh and link these components, to draw directional arrows for these links, and to specify any sequences of activity among the components. Although research methods are the primary concern of this report, the research findings reinforced the effect of perceptual processes on tactical decisions and actions (Federico, 1997).

The end result of knowledge elicitation methods is a model that represents the referent object with varying accuracy (Cooke, 1994). The more specified or formal the method used to elicit knowledge, the more systematic and complete the model and the more quantitative the results. Formal methods too divorced from actual task performance often lack validity, however, and require extensive preparation time and domain knowledge. Less formal methods, particularly task based, may yield valuable knowledge elements; but they often result in a glut of qualitative information that is hard to analyze or organize into a coherent model.

The method recommendations on knowledge elicitation for defining the common picture are based on the methods reviewed. The recommended adaptations of these methods address some of their perceived shortcomings and the information requirements unique to the common picture depicted on C⁴I displays. These methods stress a more formal approach to knowledge elicitation. In particular, they stress the need to ground the elicitation of required informational elements for the common picture in well-structured military scenarios. These scenarios should provide microworld models of the operational context, battlefield situations during the mission, and a detailed representation of that context for each key duty position.

A perceived weakness in the methods reviewed was a reliance on relatively impoverished stimulus materials. For example, Fischer and Geiwitz (1996) based their analysis of meaningful battlefield patterns only on planning-level materials, and failed to document the source or quality of materials used. The types of battlefield patterns that emerge during the more dynamic and stressful mission phases, to include mission execution, were not addressed. Similarly, Federico's work was based on "seven abbreviated and telegraphic tactical situations, each of which were written on a 5 1/2 x 8 1/2-inch numbered note card" (Federico, 1997, p. 151). While the materials used may have been adequate for their purposes, more comprehensive and tested source materials are needed to define the common picture. In contrast, the FXXITP training exercises provide a structured set of stimulus materials. The FXXITP training exercises are recommended, therefore, for both the pragmatic and more thorough methods recommended in the following sections.

More Pragmatic Knowledge Elicitation Methods

To determine user information requirements, alternative knowledge elicitation methods are recommended in order to balance effectiveness and efficiency considerations. Both the more pragmatic and thorough methods recommended, however, propose that knowledge elicitation should be structured by the factors of METT-T. A notional example of some coarse-grained informational elements for each METT-T factor was provided in Table 2, and more detailed informational elements would be expected as a result of knowledge elicitation. A pragmatic approach to eliciting FXXITP-based informational requirements might rely on subject matter experts (SMEs), such as the dedicated team of observers/controllers who routinely administer FXXITP training exercises, or the FXXITP developmental teams.

Table 3 presents a notional METT-T checklist to structure SME knowledge elicitation. For a sample of representative duty positions, SMEs could determine what informational elements were required for each aspect of METT-T during a FXXITP exercise by phase and event. At the same time, these SMEs might estimate the relevance and criticality of each informational element on a multipoint rating scale, with respect to a user's duty position and to overall mission success. They might also estimate when the informational element was needed and when it was no longer of value, in relation to the FXXITP timeline of battlefield events. In addition, these SMEs could provide estimates about information flow. These methods should identify the original source of the information, the path taken to get the information from the source to the duty position under examination, and any paths taken to distribute the information to others.

Table 3

Notional Checklist for Identifying METT-T Information Requirements

Duty Position _____		ID # _____		Mission/Phase/Event _____													
	Reqd Info	Relevant Info					Critical Info					Time Reqd	Time Recvd	Information Source		Information Destination	
	Y/N	1	2	3	4	5	1	2	3	4	5			Dir	DP	Dir	DP
Mission																	
WARNO	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
OPORD	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
OPS Overlay	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Cmdr's Intent	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
COA	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
FRAGO	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Enemy																	
Location	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Composition	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Disposition	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Ability to See	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Ability to Move	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Ability to Shoot	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Ability to Comm.	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Ability to Sustain	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Terrain																	
Observation	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Cover	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Concealment	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Obstacles	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Key Terrain	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Approach Aves	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Weather	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Troops																	
Location	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Organization	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Ability to See	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Ability to Move	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Ability to Shoot	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Ability to Comm	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Ability to Sustain	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Time																	
Plan	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
War Game	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Prepare	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Rehearse	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	
Execute																	
Sync Execute	Y/N													↑ ↓ ⇄		↑ ↓ ⇄	

Note: Info = Information; Req'd = Required; Rec'd = Received; Dir = Direction (Higher, Lower, or Adjacent Unit); DP = Duty Position; Comm = Communicate; Aves = Avenues.

To maintain a pragmatic approach, these SMEs might base their estimates solely on the off-the-shelf stimulus materials in a FXXITP training support package (vs. actual observation of a FXXITP exercise) and their own subject matter expertise. The FXXITP's detailed exercise materials should serve to stimulate the recall of information requirements by the SMEs. Their estimates might be based on the available set of battalion or brigade FXXITP exercises, or more pragmatically on a subset of exercises. Similar stimulated recall methods might be used to elicit the informational requirements of users, rather than SMEs, after the users have completed a subject FXXITP exercise.

More Thorough Knowledge Elicitation Methods

More thorough approaches to knowledge elicitation could provide a firm basis for operationally defining common picture information requirements, and supporting future training and evaluation efforts. More thorough methods would extend the pragmatic methods described to include all duty positions in a battalion or brigade unit. Additionally, more thorough knowledge elicitation methods called process tracing would require that information requirements be elicited during actual task-based performance (Cooke, 1994)³. Process tracing to elicit the knowledge of skilled performers during an exercise is informative and potentially more credible than observer data, but it may disrupt and contaminate the subject process. To elicit knowledge from nonperformers, such as SMEs observing actual or prerecorded task-based performance, process tracing is less disruptive and allows a more structured and directed approach to knowledge elicitation.

The primary method recommendation, therefore, is process tracing to elicit SME's knowledge of METT-T information requirements based on their observations of FXXITP exercises conducted by skilled performers. This method should target the METT-T aspects deemed relevant by the SME for each assigned duty position. The SME protocol might be a checklist of METT-T elements and information exchange requirements similar to Table 3, by exercise phase and event. The information elicited could supplement that gained from more pragmatic methods. It might better identify what information is considered by experts, the order in which the information is considered, and the actual rules used to combine information (Cooke, 1994).

In summary, the knowledge elicitation methods recommended crosswalking the information requirements of skilled performers elicited during FXXITP exercises with FBCB² processing and display capabilities. The recommendation to include all the key duty positions in a battalion or brigade should result in a comprehensive database that captures the informational requirements of the entire unit. In large part, this database operationally defines the information required to develop and maintain a common picture of the battlefield, within the bounded problem space. It also provides an empirical base to train and assess information management performance, such as the unit's ability to maintain a common picture of their battlefield situation.

³ Notably, a log of human-computer interactions compiled during actual task performance is a form of process tracing, although not knowledge elicitation, that is considered later in this report.

Assess C⁴I Information Capabilities

Perceived shortcomings in the C⁴I systems currently available to the Army are surfacing the need for more precise specification and testing of developmental C⁴I systems. Advocates for this need urge an *a priori* approach in which required capabilities are validated, for instance in a virtual simulation environment, prior to more costly and frequently failed field exercises or evaluations (J. Hiller, personal communication, February 18, 1997). More specifically, research on C⁴I systems should develop and apply "measures of effectiveness (MOEs) reflecting the performance of the hardware" (J. Hiller, personal communication, December 9, 1996). Notably, the Army's current C⁴I systems may not be capable of displaying many of the informational elements required to meet the common picture objective. For example, a current C⁴I system for the Abrams tank, the Inter-Vehicular Information System (IVIS), displays only a grid matrix for the geographic area depicted that provides no terrain features, such as hills, roads, and rivers.

The method recommendation to address this research issue directly assesses C⁴I performance against user information requirements. This method builds on the information requirements previously determined by applying the methods recommended in the above section. Once user information requirements are elicited and codified by METT-T, they should provide an empirical basis for assessing the extent to which a C⁴I system meets those requirements. This report's pictorial focus leads to a method recommendation that results in a set of C⁴I display codes directed at the common picture objective. These C⁴I display codes would equate to MOEs reflecting machine performance, and help justify required performance improvements.

C⁴I Display Codes

While various methods are applicable to assessing machine performance, the method recommend is an adaptation of a method developed by Burnside (1990) for assessing the capabilities of training simulations. For training assessment, Burnside's method first identified the population of tasks to be trained in a given domain, battalion-down tank and mechanized infantry units. Later, the method determined the degree to which the standards for those tasks could be met in simulation, namely the Simulation Networking (SIMNET) virtual simulation. For C⁴I system assessment, the method would begin with the population of METT-T informational requirements for a battalion or brigade, previously identified through knowledge elicitation methods. Later, the method would determine the degree to which the informational elements could be displayed by a C⁴I system, such as FBCB².

A recommended method for deriving C⁴I display codes by METT-T would require SME ratings for informational elements within each factor. Elements of required Enemy information, for example, might include: size, activity, location, unit type, time, equipment, and intent. Ratings at this more precise level should result in more reliable estimates. The criteria for estimating C⁴I display capability might use a 5-point rating scale with clearly anchored definitions for each of the five categories that track both textual and graphic display formats. Criteria might range, for example, from "Not Displayed" to "Fully Displayed Graphically." Raters would make their estimates independently by observing each of the informational elements as displayed, or not, on the target C⁴I system, such as FBCB². A display driver might be used to automatically present the

elements, as ordered on the rating form, to expedite and standardize stimulus presentation and procedure.

Decision rules are needed to consolidate the ratings for each type of informational element into each of the five METT-T categories, and in turn, into an overall METT-T assessment. The decision rules formulated by Burnside (1990) for consolidating ratings within and across categories (subtask and task categories, for Burnside's effort) could be adapted to the METT-T ratings. As noted by Burnside, such decision rules are algorithmic and can be automated to avoid manual calculation of the required estimates.

After these rules are formulated and applied, more objective and meaningful assessments of the common picture requirement should result. A notional estimate for the factor Enemy, for example, might be: "The FBCB² application graphically displays 60% of the enemy information required by a battalion commander." Estimates by duty position should help assess information requirements for any METT-T factor, or across METT-T. Estimates across different duty positions could provide a basis for consolidating information requirements by echelon, unit, or battlefield functional area.

Such estimates should provide a basis for quantifying and categorizing specific C⁴I requirements as met or not met. At lower-levels, estimates for each type of informational element rated would provide a basis for more precise requirements and, in turn, more exacting system specifications for improvements and enhancements. These more detailed estimates would also provide a basis to identify and develop digital training and evaluation methods, as discussed later. More global estimates, by METT-T category or across METT-T, might provide a more succinct and defensible assessment of C⁴I display capabilities. Assessments at this level would allow the Army to objectively report status on the common picture objective and justify support needed.

Assess Performance, Give Feedback

Measurement is essential to training and evaluation. However, direct observation and objective measurement of performance during military training exercises is difficult, particularly for command and control performance. Research methods are needed to provide an empirical account of the pictorial elements required for the common picture product and, the process by which those elements are created and maintained. Training methods are needed to provide empirical assessment and feedback on trainees' performance related to product and process requirements. The method recommendation, therefore, is to instrument C⁴I systems to compile a log of all soldier-computer interactions as an empirical basis for assessing performance and giving feedback. Before discussing this recommendation, the distinction between physical and mental "pictures" of the battlefield situation is considered.

This report's emphasis on empirical methods is based on the pictorial elements depicted on a C⁴I display. These pictorial elements on a C⁴I display constitute a physical and objective picture of the battlefield situation, albeit not necessarily an accurate one. Soldiers and their C⁴I systems determine what pictorial elements are, and are not, depicted. Each and every pictorial element on a tactical display can be empirically traced to its source, soldier or machine, including the path from

that source to the user of the display. The method recommendation will examine how this empirical data can be automatically compiled and assessed to provide performance feedback.

In contrast, the term common picture is frequently used to describe the user's mental picture of a battlefield situation or "situational awareness" (DA, 1996b). The distinction between physical and mental pictures seems blurred, for example, by an Army definition of situational awareness. "Situational awareness is the ability to have accurate and real-time information of friendly, enemy, neutral, and noncombatant locations; a common, relevant picture of the battlefield scaled to specific level of interest and special needs" (DA, 1998a, p. 5). Similarly, the Army's training requirement for situational awareness is closely related to the user's digital display (DA, 1997a):

Capability to create an accurate and high fidelity ...collaborative real-time picture of the battlespace to include weather, terrain, environment, and friendly/enemy/neutral/non-combatant situational and status information The common picture provides understanding of available information in terms of the battlespace: width, depth, height, position, time, terrain, materiel, weather, obstacles and barriers The relevant common picture must be scaleable to appropriate levels of command, tailorable by function and personal preference, and based on variable user defined parameters.... (pp. 5-6)

Mental pictures of a situation or situational awareness, however, are subjective and difficult to measure (Adams, Tenney, & Pew, 1995; Endsley, 1995). They are influenced by individual differences such as expertise and motivation, and ideally by the physical picture on a C⁴I display. A telling distinction, the same picture on a C⁴I display may result in very different mental pictures by different users, such as an expert versus a novice. In sum, the distinction is fundamental to this report's emphasis on the common picture as an empirical construct based solely on the physical pictures, the pictorial elements, on a C⁴I display.

Instrument C⁴I Systems

Digital C⁴I systems are uniquely suited to automatically collect data for performance assessment and feedback. Computers can, and frequently do, routinely log all user inputs and system responses. For this report, instrumentation of a C⁴I system equates to a system log of all soldier-computer interactions correlated with the simulated battlefield situation in which they occur. No currently fielded C⁴I systems are instrumented, however. The method recommendation, therefore, is to instrument C⁴I systems. This recommendation includes all C⁴I system variants—operational, developmental, and training.

Method recommendations for applying instrumented C⁴I systems begin with a discussion of the common picture as a meaningful, measurable, and collaborative product. This discussion describes how instrumented C⁴I systems could automatically capture this product at any moment during a training exercise as well as the collaborative process by which this product is created and maintained. Next, methods for assessing performance and providing feedback based on

instrumented data are considered. Finally, a working example of this method is described called automated pictorial comparisons, based on normative or criterion standards of a common picture.

A Meaningful, Measurable, and Collaborative Product. The physical picture depicted on a C⁴I tactical display equates to a meaningful, measurable, and collaborative product. A display depiction is meaningful if it provides a representation of the external world that perceptually maps to the mental model of the viewer. A display depiction is measurable if it provides access to its underlying database. Key data for assessing a computer-based tactical display includes the data elements depicted on the display and their collaborative source. Source data includes a record of all soldier-computer interactions required to generate the user's display, or intra-system data. Source data also includes all information from external sources such as messages received from other users and the path to that source, or inter-system data. A composite database of intersystem and intrasystem data is readily obtained if C⁴I systems are instrumented to provide, in essence, a log of all soldier-computer interactions (Lickteig, 1996).

Examples of intersystem data include the receipt and content of mission orders, graphic overlays, and recurrent updates on enemy and friendly locations and identities. They also include requests for information and for support, such as indirect fires, close air, and supplies. Intersystem data also includes what information was distributed by each C⁴I user as intersystem communications to others. Such data disclose what battlefield information was available and *not* available to C⁴I equipped soldiers, and when that information was available.

Examples of intrasystem data include when and if intersystem data received by a user's C⁴I system, and therefore available, was "opened" for presentation on the user's display. They also include when and *if* that information was actually visible in the user's display "window" based on the map areas and scales selected by the user. Intrasystem data also disclose what information was solicited and examined by the user based on a log of user interactions, such as the activation of terrain analysis tools or the call up of friendly status menus.

This composite database of the elements depicted on the tactical display by source and path represents a measurable product achieved through collaborative information processing and management. This collaboration includes all individual and collective soldier-computer interactions required to create and maintain the battlefield pictures depicted on a unit's C⁴I displays. In addition, this database provides a quantifiable and tractable link between the informational requirements of the users and the informational capabilities of the tactical display. Notably, this composite database is used to support the training methods recommended later in this report. Intrasystem data would support individual training analysis and feedback methods. Inter- and intra-system data would support small group and collective training analysis and feedback methods.

A Working Example: Automated Pictorial Comparisons. A working example of collaborative products based on this composite database is automated pictorial comparisons of the battlefield situations depicted on users' C⁴I displays at any time during a simulated mission exercise. Such comparisons are analogous to the "compare document" function provided by many word processing applications for comparing textual products. For most text applications, this function automatically compares multiple versions of a product and highlights detected

discrepancies for both on screen and hard copy presentation. Users are often provided highlight options, such as color, bold, underline and strikethrough, to accent discrepancies and identify the source or author.

Figure 1 provides a simple example of how automated pictorial comparison might illustrate a key discrepancy between the battlefield representations depicted on the C⁴I displays of two different users at a selected moment during a mission. In this figure example, a company commander's display at 1200 hr depicts four Enemy tanks, a platoon sized unit, that is not simultaneously depicted on another display at the next level of command, the battalion commander. Such a potentially important discrepancy would be automatically detected and highlighted by the proposed compare picture routine. Instrumented C⁴I systems could readily extend this example to compare the battlefield situations depicted on the C⁴I displays of each user at any time during a simulated mission exercise.

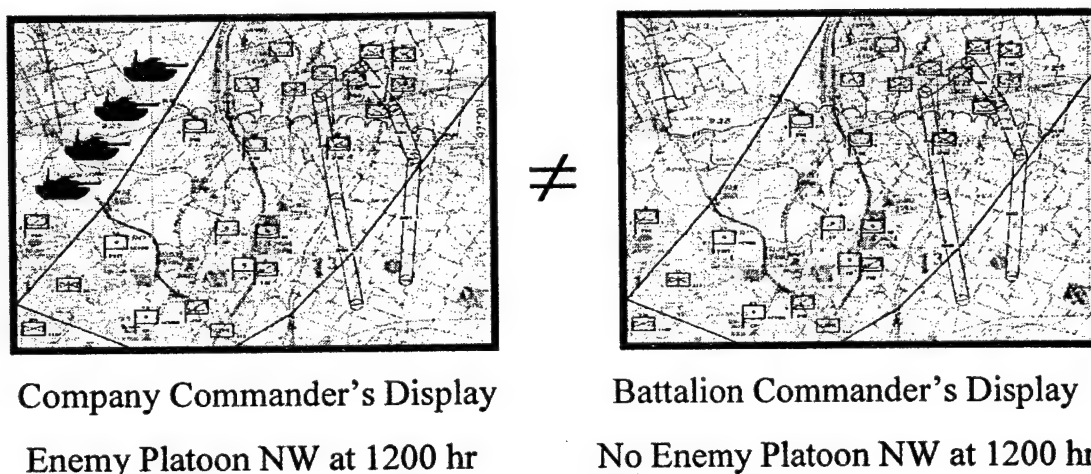


Figure 1. An example of automated pictorial comparisons on notional C⁴I displays.

This report's method recommendation for automated pictorial comparisons underscores the need for, and potential of, instrumented C⁴I systems. A comprehensive log of soldier-computer interactions correlated with the simulated battlefield situation in which they occur would provide an unprecedented empirical base for training and evaluation. More definitive and meaningful comparisons, however, require the logging of intrasystem data to accurately assess actual display content. In contrast, pictorial comparisons based only on intersystem data are speculative. For example, work by Brown, Metzler, Riede and Wonsewitz (1996) provide excellent examples of pictorial comparisons for training feedback based on intersystem data. Such intersystem comparisons, however, disclose only the information that *should* have been available to a user, rather than the information that was *actually visible* to each user at any moment during a simulated battlefield exercise.

Pictorial comparisons are not limited to product comparisons, such as momentary snapshots of an exercise. More process directed comparisons might illustrate the flow of information across the unit, such as when and how the company commander received enemy information that was not

received by the platoon leader. A different type of process comparison might highlight intrasystem discrepancies such as the information received by a user's C⁴I system that was never opened or actually visible in the user's C⁴I display window. This comparison requires only an automated analysis of the map-based location of the information depicted relative to the map areas actually displayed to the user.

Notably, pictorial comparisons might be based on normative or criterion standards. One method for normative comparisons might simply compare C⁴I pictures across a unit or any designated set of unit members, such as the battalion commander and the company commanders. Such comparisons would identify and highlight what is *uncommon* about a unit's common picture of the battlefield. Although some differences between duty positions are to be expected, as previously discussed, the comparisons can be set to address only selected types of commonly required information. One type might compare enemy vehicles depicted, or not depicted, on unit members' displays at any time during the exercise. Other types of normative comparisons within a unit might include any other METT-T factor or informational element listed in Table 2.

Criterion standards for assessing task performance related to the common picture would provide another basis for pictorial comparisons. Such comparisons require an accepted criterion for what should be depicted on a C⁴I display. The methods previously recommended for determining information requirements through expert knowledge elicitation were designed to help establish such standards. This expert analysis included consideration of the corresponding C⁴I pictorial elements associated with the information required. One goal of that effort was to help develop a model of required information exchanges by duty position for battalion or brigade unit training. Later in this report, method recommendations for developing and applying a computer-driven version of this information exchange model to performance assessment and feedback are presented. Given this model, criterion-based pictorial comparisons would match trainees' product and process performance with corresponding standards from the information exchange model.

The remainder of this report will examine how to apply automated pictorial comparisons, and additional examples of instrumented C⁴I measures, to efficiently and effectively assess information related task performance and provide feedback at individual, small group and collective levels.

Communicate the Common Picture

This section identifies two key research issues to improve the ability of soldiers and C⁴I systems to pictorially communicate battlefield situations. First, the soldier's mental model of the battlefield environment should shape the tool's microworld representation of this environment to render it more meaningful. This issue is identified as the need to shape C⁴I representations. Second, the soldier's tool or C⁴I system should shape or train the worker to recognize and understand the tactical patterns and situations depicted on C⁴I displays. This issue is identified as the need to shape mental models, and is regarded in this report as an individual training issue. Method recommendations to address these issues are based on the literature reviewed, and more detailed method descriptions are provided and referenced to clarify the method recommendations and support their application.

The process of forming meaningful computer representations is communication between users and computers. Method recommendations to improve soldier-computer communication will stress the interaction, the dialog, between human and computer representations. A common example of how a user's model shapes a computer's representation is a backyard, deck-design program at the local hardware store. Examples of how the computer shapes internal models are as common as messages received from e-mail or a C⁴I system. A less common, and more pedagogical, example might be a tactical display that effectively communicates terrain relief by allowing the trainee to iteratively transform, as desired, a 2-dimensional (D) topographic map with contour lines into a 3-D perspective view of terrain elevation. The digital training methods recommended provide trainees and trainers the ability to manipulate time and space in the 4-D battlefields created by digital technologies, such as C⁴I systems and warfighting simulations.

Method recommendations to shape C⁴I representations begin by assessing how well C⁴I systems pictorially communicate meaningful information to the user. Then, research methods are recommended to assess the tradeoffs between the Army's analog information formats versus current and future digital formats. Method recommendations to shape users' mental models to match C⁴I representations rely on documented methods for developing automatic processing capabilities to train pattern and situation recognition skills. In addition, these recommendations capitalize on the ability of digital technologies to provide trainee and trainer control over the tactical patterns and battlefield situations depicted on C⁴I displays. A variety of methods to control or manipulate training presentation formats are recommended including: a reduced stimulus environment, animation, perceptual augmentation, and time compression and expansion.

Shape C⁴I Representations

The importance of perceptually mapping the worker's mental model and the microworld work model was previously considered. Unfortunately, numerous failures in commercial computer systems are attributed to their indifference to human information processing and problem solving. In contrast, a cognitively engineered interface is superior in performance, satisfaction, and workload to interfaces that are not cognitively engineered (Gerhardt-Powals, 1996). One compelling example of a communicative representation is a direct-manipulation interface, such as a desktop or battlefield metaphor. By depicting direct links to supporting databases, a direct-manipulation interface aids information access, extraction, and distribution; by depicting a coherent conceptual schema, it aids information detection, abstraction, and integration (Lucarella & Zanzi, 1996).

As a metaphoric battlefield, the common picture on a C⁴I display should provide a microworld battlefield representation with METT-T object domains. This representation should afford direct manipulation of these METT-T objects, at the level the user chooses to transfer goal-relevant information (Meshkati, 1996). Advantages of such a representation include a stable structure that naturally nests required information and process elements (Bennett, Nagy, & Flach, 1997). The metaphoric battlefield would also readily support the use of graphic landmarks to aid navigation among dispersed work "areas" while maintaining orientation. Useful landmarks might include a picture-in-a-picture overview of the entire battlefield area relative to the area currently displayed in the interface window, or depiction of a menu hierarchy relative to current location on a

multipage menu. For a recent review of methods that support user configuration of their work representations, see Pejtersen and Rasmussen (1997).

The initial concern is to provide a method that allows the user to shape the microworld representation of the battlefield environment on a C⁴I display to render it more meaningful. In general, the cognitive engineering principles and guidelines for interface design and training were derived from a useful set of such methods (Gerhardt-Powals, 1996; Lucarella & Zanzi, 1996). In particular, the following section describes a further modification of the method developed by Burnside (1990) and adapted to the C⁴I display codes, previously discussed. This method should result in C⁴I display decodes based on the user's ability to understand and use the information displayed.

C4I Display Decodes

This method recommendation begins with the set of METT-T informational elements previously identified as C⁴I display codes for a target digital system, such as FBCB². This method will conclude with SME or user estimates of how understandable and useful they find each METT-T informational element, as currently displayed. These decode ratings should identify perceived strengths and shortcomings in C⁴I display representation. These results would also provide a basis for comparing current C⁴I display formats with traditional analog formats (generally paper-based), and alternative digital display formats.

Methods for deriving C⁴I display decodes would again require SME or user ratings at the level of discrete informational elements within each METT-T category. Criteria for estimating C⁴I display understandability and usability might use separate 5-point rating scales with clearly anchored definitions for each point. For understandability, criteria might range from "Not Understood" to "Fully Understood." For usability, criteria might range from "Not Usable" to "Fully Usable." Raters would make their estimates independently by observing each of the informational elements as displayed on the target C⁴I system, such as FBCB². The rating form should request comments on lower rated elements. A display driver that automatically presents the elements, as ordered on the rating form, might again expedite and standardize stimulus presentation and procedure.

Decision rules, similar to those developed for C⁴I display codes, could consolidate ratings by informational element into each of the five METT-T categories and an overall METT-T assessment. After these rules are formulated and applied, estimates of understandability and usability could be compiled across rated duty positions and information levels, as required. Overall, such estimates might identify global and local problems in understanding and acting on C⁴I battlefield representations.

Alternative Format Comparisons

Research methods are also required to help users shape the microworld representations displayed by C⁴I systems. Empirical assessment of the tradeoffs associated with alternative display formats might substantiate a requirement for format revision and its benefit. For such comparisons,

the methods recommended are task-based performance evaluation based on measures of speed, accuracy, and degree of understanding and usability. The number and type of required comparisons would depend on the degree of decoding deficiencies previously identified.

Conventional formats for military information rely heavily on alphanumeric characters, including free-text and tabular formats (Gerhardt-Powals, 1996). In addition to alphanumerics, the military also uses prescribed graphical presentation formats to pictorially depict key METT-T aspects of a battlefield situation (DA, 1996d). These formats include a standard set of control measures to provide a visual blueprint of the mission, and a standard set of icons symbolizing various weapon platforms to differentiate unit type, size, and enemy versus friendly alignment. They also include symbols and legends illustrating key terrain features and patterns of tactical significance, and conventions for timelines and temporal events (e.g., proposed future locations).

Currently, most C⁴I systems and displays have adopted the standardized text and graphic formats used by the military. It remains an empirical question, however, how understandable and usable such symbology is when converted to electronic display formats. A straightforward set of empirical comparisons to identify any C⁴I decoding deficiencies relative to the military's standard presentation formats is recommended (DA, 1996d). Given the display limitations of current C⁴I systems, such as IVIS and FBCB², such comparisons may disclose that paper-based formats are more understandable and useful, at least for some text and graphic items. A more realistic context for digital formats should assess information decoding and use on a cluttered tactical display in which multiple items are concurrently displayed.

A related empirical issue is whether digital technologies might provide better information formats than conventional military formats and symbols. While table and matrix presentation formats afford precise and highly detailed information, such formats may not provide an optimal representation for understanding and using the information presented. Tabled information is often decontextualized from relevant aspects of the task environment, such as the geometry of the battlefield. For example, a table format called an execution matrix is used to coordinate unit activities. A simple example of an execution matrix might be a 5 x 5 table that prespecifies for each of five units, their expected locations and activities for five successive mission segments. The inherent stability of alphanumeric formats (Kozma, 1991), however, may not readily convey the dynamic patterns implicit in an execution matrix.

An empirical issue, therefore, is to determine how the unique information processing power of digital technologies might provide alternative formats to standard military symbology to increase user understanding and use of the information displayed. An alternative digital format for an execution matrix, for example, might be an animated projection of successive unit locations and activities on a user's C⁴I display (Leibrecht, Meade, Schmidt, Doherty, & Lickteig, 1994). Compared to a tabular format, such an animation might significantly improve users' speed, accuracy, and degree of understanding and usability.

Additional examples of alternative digital formats will be considered in subsequent sections that attempt to apply digital technologies to the common picture objective. The point here is that empirical comparison might identify and substantiate the requirement for alternative digital

formats. Such comparisons, based on SME ratings and user performance, are methods for shaping the microworld representation of the battlefield to the worker's mental model of the task environment.

Shape Mental Models

This report's application of digital technologies to individual training begins here with issues related to visual recognition of the battlefield representation depicted by C⁴I displays. The methods recommended in this section stress that information processing and display capabilities of the Army's C⁴I systems should shape or train the worker to better understand and use the information and representations displayed. For enhancing visual recognition of the battlefield representations depicted by C⁴I displays, this section reviews training methods from two distinct areas. First, training methods that promote an automatic recognition of patterns and situations may provide novices many of the component skills underlying expert performance (Fisk & Rogers, 1992). Second, digital training technologies that enable trainees and trainers to control or transform microworld representations may provide unique solutions to training pattern and situation recognition (Kozma, 1991).

Automatic processing theory assumes that training entails building and expanding a basic bank of component skills that become networked and organized over time in relation to task goals (Fisk & Eboch, 1989). Lower level or component skills combine with others to form a component at a higher level. More consistent task elements, such as steering or braking a vehicle, result in more automatic processing for task performance. More inconsistent and novel task elements, such as navigating in an unfamiliar city or terrain, require more controlled or deliberate processing for task performance. For the Terrain factor of METT-T, for example, lower level component skills may equate to recognition of single-feature patterns, such as a hill or slope. Higher level skills may equate to recognition of multiple-feature patterns, such as an avenue of approach or road network. Progressive automaticity should network and organize recognition skills across both of these levels, and also support situation recognition skills at a higher level.

Improvements in skilled performance are primarily due to developing automatic processes across a bank of supporting component skills (Fisk & Eboch, 1989). In contrast, controlled processes show little improvement with practice, and controlling resources are limited. Some benefits of automated processing are:

...attentional requirements are minimized; performance becomes faster and more accurate; performance becomes less susceptible to situational stress; and performance becomes more durable or less susceptible to memory loss. (Rogers, Maurer, Salas, and Fisk 1997, p. 22)

Although the benefits of habit have long been appreciated, training programs are rarely structured to fully leverage these benefits. For example, a key training fallacy is that practice makes perfect (Schneider, 1986). A poorly structured regimen of practice often results in little or

no improvement in performance. Methods for training automatic processing provide explicit guidelines on how to structure training events for the "consistent practice" required to improve performance (Schneider, 1986).

Second, the unique capabilities of digital technologies to represent and link internal and external realities afford powerful solutions for shaping the worker's mental model to match actual job requirements and settings (Fletcher, 1994; Rasmussen & Pejtersen, 1995). The work of Kozma (1991, 1994) includes training methods that allow trainees to visualize and transform microworld representations. One goal of such methods is to enable novices to visibly "see" what only experts can visualize. For example, when physicists are confronted with problem situations they perceive patterns based on underlying structures that may have no direct, concrete referent in the real world. Microworld representations of the same problem space, however, have allowed trainees to visualize and manipulate constructs such as force and motion directly. Training based on such a microworld representation results in improved understanding and use, relative to more traditional training methods (Kozma, 1994).

Notably, there are shortcomings and unintended consequences with a reliance on digital technologies that training methods must avoid, as previously discussed. For example, there is spreading concern that soldiers' progressive dependence on digital technologies may deter the acquisition and maintenance of conventional soldier skills, such as map reading (Ford, Campbell, & Cobb, 1998). It is a valid concern, but one that does not fully reflect the training potential of digital technologies. The method recommendations stress that digital technologies are an exemplary medium for acquiring and maintaining digital *and* conventional skills, such as pattern and situation recognition. Soldiers on the battlefield must possess autonomous skills to overcome inevitable degradations in equipment, such as C⁴I systems. The Army must await the fielding of more advanced and fully compatible C⁴I systems. However, it can leverage the capabilities of digital technologies now to train both digital and conventional skills, such as pattern and situation recognition.

Finally, the potential realism of C⁴I display training seems underscored by emerging trends in information age warfighting, such as increased stand-off ranges and indirect vision systems. Electronic displays and their microworld representations may be the dominant visual channel in the beyond-line-of-sight warfare envisioned for the future battlefield.

Pattern Recognition

This section begins by reviewing training methods for pattern recognition based on automatic processing research, and then recommending how to apply these methods to digital technologies to train the recognition of tactical patterns. Next, this section examines how digital technologies can allow trainees and trainers to control or transform patterns, and how this capability might be used to train the recognition of tactical patterns. While the primary focus here is the recognition of tactical battlefield patterns as represented on C⁴I displays, any acquired skills should generalize to other representations, such as paper maps, and actual battlefield situations.

Automatic Processing. Soldiers must be able to recognize the tactical battlefield patterns depicted on their C⁴I displays to use that information appropriately. Skilled pattern recognition characterizes expert performance, yet the Army provides no formal training on recognizing and using the tactical patterns that appear on the battlefield (Fischer & Geiwitz, 1996). In support of the common picture objective, digital technologies provide an exemplary medium for developing pattern recognition skills. Recommended methods for applying digital technologies to this issue are based on modifications of paper-based methods developed by Fischer and Geiwitz (1996) for pattern recognition training, and the methods used by Fisk and Eboch (1989) to develop automatic processing of map reading skills related to map legends.

The tactical pattern recognition training of Fischer and Geiwitz (1996) stressed extensive practice with feedback, information about the meaning of patterns, the perceptual aspects of patterns, and prototypical patterns. The student text provided prototype or exemplar schematics of each terrain pattern accompanied by a definition and a description of the critical features unique to that pattern. The approximately 40 hours of training began with single-feature patterns such as a hill or ridge, and progressed to multiple-feature patterns such as canalizing terrain or an avenue of approach. Trainees then completed workbook exercises that required them to identify terrain features on military topographic maps, and mark patterns of tactical significance within designated map areas, such as unit boundaries.

Four separate measures immediately after training, and a retest nine months later were used to assess this training program (Fischer & Geiwitz, 1996). The results were promising. Experimental participants from four reserve officer training corps (ROTC) courses attained terrain pattern recognition skills comparable to a sample of Army Captains who had completed officer basic and advanced training, and several years in field assignments.

The extended description of the tactical pattern recognition training of Fischer and Geiwitz (1996) reflects a recommendation that such methods should be applied to digital technologies. Their approach to pattern meaning centered on the military significance of each of 40 terrain patterns, including their tactical advantages and disadvantages. Their approach and catalog of patterns for Terrain is recommended, but additional patterns are required for the other factors of METT-T. The overall METT-T organization, or network, of the patterns to be trained should reinforce their relevance and application to military operations and related training. This report's focus on the common picture objective also requires that pattern recognition training methods address patterns as depicted on a C⁴I display. Benefits derived from a digital application of pattern recognition training might include an economy in training delivery, support, assessment, and management. This digital conversion would also support training method recommendations to supplement pattern recognition skills, such as automatic processing and pattern transformation training.

Digital technologies may be the only realistic medium to effectively and efficiently employ the training methods required to develop automatic processing for a large trainee population. Methods to develop automatic processing and improve performance, for example, require that trainees experience consistent pairings between task stimuli and responses, and relatively immediate feedback across multiple training trials. Inconsistent pairings and inadequate feedback

do not result in improved performance (Fisk & Eboch, 1989). Notably, automatic processing methods invariably employ a visual memory search paradigm in which trainees must decide if an item or image stored in memory appears in a displayed set of items, including target and distractor items. This paradigm meshes well with a focus on pictorial communication via C⁴I displays, in general, and recognition training, in particular.

Given their documentation (Fisk & Eboch, 1989), the authors forgo a more detailed discussion of training methods for automatic processing. Their methods as applied to map reading, however, are particularly applicable to METT-T based pattern recognition on a C⁴I display. An adaptation of these methods should apply training guidelines for automatic processing to avoid the training fallacies documented by Schneider (1986). The rationale for applying automatic processing methods to recognition training includes the more general benefits cited by Rogers et al. (1997), and previously noted. Benefits more specific to pictorial communication objectives might include faster, more accurate, and less variable pattern recognition performance, as found by Fisk & Eboch (1989). Their work also demonstrated that trainees with automatic processing were less susceptible to information overload.

One might hypothesize similar benefits if users can more automatically process the visual patterns on a C⁴I display. Of special interest, pattern recognition performance might be less susceptible to degradation typically caused by larger amounts of information on a C⁴I display. In contrast to more controlled information processing, automatic processing is a relatively capacity-free process, and visual search for key patterns on a display becomes markedly non-serial. With automatic processing, patterns "pop out" of the display (Fisk and Eboch, 1989, p. 4).

Pattern Transformation. Training methods should also apply digital technologies to transform and augment METT-T patterns depicted by C⁴I systems and military simulations. Such capabilities provide unique and potentially powerful methods to help trainees shape their mental models and mental processes to external task requirements. The methods recommended apply digital transformation capabilities to train recognition of the battlefield patterns on C⁴I displays.

One of the more difficult recognition aspects of METT-T battlefield patterns may be terrain appreciation. It is particularly difficult to perceive the elevation of terrain, terrain relief, from 2-D map representations (Lickteig & Burnside, 1986). Traditional methods for training terrain appreciation and pattern recognition rely on comparisons between 2-D and 3-D perspective views of the same pattern or similar patterns. Presentation formats for such comparisons include: paper maps and illustrations, as used by Fischer and Geiwitz (1996); paper maps and actual terrain, as used in field-settings; and paper maps and terrain photographs.

A more innovative method for training terrain appreciation used 360-degree photograph sets from various field locations in which a set included 120 sequential photographs with 3-degrees of separation (Lickteig & Burnside, 1986). The photos were loaded on a laser disc and trainees scanned a location by using a joystick that controlled scan rate and direction to determine their location on paper maps. This same report also describes a method for training pattern recognition that used cardboard mockups of hills painted with contour elevation lines. Video recordings of the mockups were made from perspective and overhead views and then loaded onto laser disc.

Trainees controlled the video replays using joysticks to scan between 2-D and 3-D perspectives of the mockups, and then identified similar hilltop patterns on paper maps.

However, there are substantial limitations to developing and delivering both the traditional and more innovative training methods just described. Field-based training methods are inefficient, requiring physical relocation of the trainees to multiple terrain sites, and limited to the types of terrain features available in the training area. More traditional map and photograph comparisons are often based on a small number of photographs that provide little or no control over viewing perspective or visibility conditions. More innovative methods, such as laser-disc video, overcome some of these limitations, but entail substantial development costs, even for a small sample of training and test materials. More importantly, the training effectiveness of most map reading and terrain appreciation methods is limited (Fischer & Geiwitz 1996; Lickteig & Burnside, 1986).

Digital training technologies may provide more efficient and effective methods for training terrain pattern recognition and map reading. Efficiencies are expected, in part, because the digital terrain databases in more advanced C⁴I systems and training simulations are designed to store, display, analyze, and transform terrain patterns. Expansion and refinement of these databases and the ability to process and manipulate them is an ongoing effort. Growing reliance on simulation and C⁴I systems, yoked by identical digital terrain databases, should support pattern recognition training in simulated battlefield settings anywhere in the world and under a variety of realistic conditions. More effective training methods are the primary concern, however.

The method recommended here is to apply the ability of digital technologies to pictorially transform battlefield patterns to train pattern and situation recognition skills. Battlefield patterns such as terrain relief, mobility corridors and intervisibility are readily analyzed and portrayed by digital technologies. Training methods designed to help soldiers appreciate terrain relief, for example, should allow trainees to visualize and control transformations between 2-D and 3-D views on a C⁴I display. These transformations might resemble a progressive "morphing" of images, as commonly seen in many television commercials, between 2-D and 3-D perspectives of the terrain. By actually displaying the otherwise invisible or mental *process* of transforming a flat topographic map into visible terrain relief, digital technologies can pictorially lead the trainee through the required mental transformations. Allowing trainees to control the pace and nature of such transformations may equate to cognitive engagement and customization of training. The unique ability of digital technologies to lead the process of transformation may approach the root definition and meaning of education (*educere*--to lead forth).

Situation Recognition

This section begins by examining the dynamic nature of battlefield situations and how situational changes are reflected in METT-T changes. Methods for training situation recognition are reviewed and particularly how these methods focus on the trainee's perceptual processes. Next, extensions of automatic processing theory that address more complex tasks such as situation recognition are reviewed, and recommendations are made for applying these methods to train the recognition of battlefield situations. After considering how digital technologies can allow trainees and trainers to control or transform battlefield situations, recommendations are provided on how

this capability might be used to train the recognition of battlefield situations. Again, the immediate concern is the recognition of battlefield situations as represented on C⁴I displays, but any acquired skills should generalize to other representations, such as analog situation maps, and actual battlefield situations.

Soldiers must be able to recognize and respond to the battlefield situations depicted on their C⁴I displays. For related METT-T informational elements, multiple-feature pattern recognition might be regarded as a relatively focused task, or part-task requirement. Across METT-T factors, situation recognition might be regarded as an integrated task, or whole-task requirement. The total battlefield situation generally exceeds the sum of its METT-T parts, particularly the informational elements displayed by the C⁴I system at any isolated moment during the battle. The methods recommended for training situation recognition, therefore, stress the unique ability of digital technologies to represent and accent the patterns of change within and across METT-T factors over time.

Battlefield situations are dynamic, and adequate mental and microworld models of the situation must reflect such dynamics. More comprehensive mental models go beyond a depicted situation or state to include the dynamic processes underlying changes or transitions between situations or states. A mental model of the battlefield situation, therefore, should recognize the underlying state changes in METT-T factors and informational elements over time and be able to project future changes. A recommended approach to training situation recognition stresses that transitions between states or situations may be the most important aspect in the development of a mental model (Kozma, 1991). Recommended training methods for situation recognition allow users to visualize and manipulate METT-T parameters to explore and refine their internal model of a battlefield situation. These methods are directly linked to the battlefield situation, as depicted on a C⁴I display or digital workstation.

Methods for recognizing battlefield situations emphasize the need to focus a trainee's attention on those factors or informational elements considered typical of, or critical to, representative situations. For example, Klein and Calderwood (1988) state such training should stress sensitivity to the critical factors that distinguish prototypical situations, in order to conceptualize situations quickly and accurately. For training situation recognition for firefighters, training might stress identifying the type of fire. For maneuver commanders, training might emphasize enemy composition or intent. Other types of critical information might be identified by the recommended C⁴I display codes that targeted "Critical Information" and "Relevant Information" based on FXXITP exercises.

Consistent with this report's focus on pictorial communication, Klein and Calderwood (1988) stress that the decision-making of experts is triggered by their primed recognition of perceptual patterns in complex task environments. Similarly, Federico's (1997) work on metacognitive models of situation assessment suggests that perceptual processes are the primary determinant of tactical decisions and actions.

Accordingly, the methods recommended for situation recognition focus on the trainee's perceptual processes and the ability of a C⁴I display to reflect and guide those processes. To aid

conceptualization and recognition of situations, these methods direct attention to METT-T structure and the changes in METT-T that create dynamic battlefield situations. These methods should also expand and integrate lower-level pattern recognition skills in relation to task goals, including situation recognition. They should also foster automatic processing skills honed by consistent practice via digital training technologies.

Automatic Processing. Extensions of automatic processing theory and findings have demonstrated its applicability for training complex tasks such as situation recognition (Fisk & Eboch, 1989; Fisk & Eggemeier, 1988). The key method to such extensions is the identification of higher-order consistencies and their structured application in the form of consistent practice. For a more detailed description of the interview and observation methods used to identify consistent higher-order components see Fisk & Eggemeier (1988). A pertinent application of such methods to identify higher-order consistencies in interface display and controls for command and control tasks was demonstrated by Eggemeier, Fisk, Robbins, & Lawless (1988). Their analysis of refueling scenarios for air traffic controllers identified consistent task elements for: (a) estimating direction, heading, and speed; (b) detecting turn initiation, direction, and completion; (c) knowledge of interface controls; and (d) knowledge of displayed symbol systems. They stress such consistencies are inherent to real world activities and are the glue that binds successful systems.

The methods of Eggemeier et al. (1988) seem directly applicable to identifying METT-T consistencies for training situation recognition with C⁴I displays and related digital technologies. In particular, their examples illustrate how situation recognition may depend on rapid and accurate processing of the spatial information graphically depicted on tactical displays. Such consistencies may provide the basis of expertise in perceiving, comprehending, and projecting current and future situations (Endsley, 1995).

To identify consistent higher-order components related to situation recognition, a recommended adaptation of the Fisk & Eggemeier (1988) methods would use interviews and observations directed at ground forces and C⁴I displays. More specifically, expert interviews and observations would target the FXXITP exercises and a selected C⁴I system, such as FBCB². These methods should result in a set of higher-order consistencies for command and control tasks that parallel and expand the types identified by Eggemeier et al. (1988) for air traffic controllers.

Method results should also identify higher-order consistencies in the interface controls and display symbol sets of the subject C⁴I system for depicting and manipulating METT-T information. An examination of required enemy information during FXXITP exercises, for example, might identify consistent task elements for estimating the enemy's direction, heading, speed, size, activity, location, unit type, and equipment. Similarly, analysis of the required terrain information should help identify consistent task elements for recognizing single- and multiple-feature terrain patterns such as cover and concealment, mobility corridors, and key terrain.

Once task consistencies are identified, they would become the building blocks for training situation recognition based on automatic processing methods (Fisk & Eboch, 1989; Fisk & Eggemeier, 1988) and the training guidelines outlined by Schneider (1985). Digital training stations, and even C⁴I systems, can be customized to consistently map their representations of the

task components selected for training. They can provide repetitive practice that automatically provides training analysis and feedback based on the user's response to those training stimuli. Grounding these methods in actual C⁴I systems, FXXITP exercises, and METT-T should help develop and integrate situation recognition skills in support of the common picture objective.

Situation Transformation. Training methods should also exploit the ability of digital technologies to transform and augment the situation patterns depicted by C⁴I systems and digital workstations. The methods recommended here stress the need to recognize situational transitions based on changes in METT-T factors over time, and the ability to project future changes. These methods should help trainees build more accurate and temporally comprehensive mental models of a battlefield situation.

Strategies for training recognition of dynamic situations suggest the trainee's attention should be directed to variations in the informational elements that specifically reflect or cause a change in the situation (Kass, Herschler, & Companion, 1991; Klein & Calderwood, 1988). One method for directing attention is a reduced stimulus environment that limits the informational elements displayed to only those required for task completion, a form of part-task training. In a SIMNET environment, Kass et al. found that pattern recognition training (i.e., muzzle flashes) with a minimum of extraneous stimuli, improved the ability of trainees to reliably detect this critical change later in a more complete and realistic battlefield environment. This method illustrates how digital technologies, such as virtual simulation, are a versatile and flexible medium for directing attention to informational features that reflect and cue changes in a battlefield situation.

A more compelling example of part-task training methods for recognition of critical changes is the work of Walker and Fisk (1995) for training football quarterbacks to "read" the defense to identify open receivers. Their training stimuli were limited to eye-level projections of the playing field during the few seconds a quarterback has after the snap to identify the emerging patterns of coverage. Player movements were depicted in real-time and after recognizing the coverage pattern, the quarterback responded by identifying the designated receiver. These methods could be readily adapted for digital simulation and C⁴I systems. For example, digital method adaptations for recognizing enemy intent in dynamic battlefield situations could rapidly depict and reconfigure enemy activities in the form of vignettes extracted from FXXITP exercises. Trainees' repeated exposure to typical and/or critical variations in enemy activity might improve their ability to read enemy intent.

Related training methods for transforming situational changes are also recommended. As previously noted, animated projections of a friendly unit's successive locations and activities might provide a useful method for understanding friendly intent. Similarly, status changes in key items such as ammunition, fuel, equipment, and personnel status can be graphically communicated by a C⁴I display (Leibrecht et al., 1994).

Perceptual augmentation is another method for directing attention to changes in depicted situations. Pertinent examples of perceptual augmentation applied to a C⁴I display, namely the Extended Joint Surveillance and Attack Radar System, are provided by Kirlik, Walker, Fisk and Nagel (1996). They transformed the display to provide additional information to help users

determine when displayed enemy vehicles necessitated action by the trainee. This additional information included four types of perceptual augmentation: (a) locomotion augmentation that marked which areas the enemy vehicle could and could not enter, (b) weapons range augmentation that encircled the vehicle's weapon range, (c) penetrability augmentation that differentially highlighted friendly vehicles as penetrable or not penetrable by the enemy vehicle, and (d) priority augmentation that superimposed on friendly vehicle icons their relative importance. Their results, based on nonaugmented trials, showed that visual augmentation increases the acquisition of decision-making skills, and resists performance decrements from larger threat arrays.

Extensions of such perceptual augmentation methods are recommended to train situation recognition on C⁴I displays and digital workstations. Perceptual augmentation might highlight significant changes in the informational features that depict the battlefield situation. Currently, some C⁴I systems highlight the icons and symbols associated with recently received information, for example. For training, prerecorded simulation exercises might highlight variations in key METT-T features or patterns during preview or review of an exercise. Similarly, a form of process tracing during the earlier stages of training might model and highlight the role and actions for a trainee's duty position on a C⁴I display or digital workstation.

Training methods that compress and expand time, to above- and below-real-time presentation rates are also recommended. Digital technologies readily manipulate time in 4-D microworld models and simulations. For example, Schneider's (1985) methods for training air traffic controllers, compressed simulated time by a factor of 100 to train visualization of flight patterns (e.g., where should an aircraft turn). Time compression methods may enhance, or make possible, the recognition of situational changes during mission segments with a slower pace. Time compression also allows trainees to experience more training trials than possible with real-time representations (Schneider, 1985). Changes on a battlefield, however, occur at very uneven rates. During intense segments of a battle, such as contact and engagement, novice trainees might benefit from methods that slow time presentation rates. In sum, methods that allow a trainee to *control* time and space patterns in microworld representations might accelerate the transition from novice to expert skill level for situation recognition.

Notably, the methods documented by Walker and Fisk (1995) demonstrate how training can, and often should, combine situation transformation methods, such as stimulus reduction, with automatic processing methods. The ability of digital technologies to automate many of the more exacting training development steps required for automatic processing and situation transformation methods supports a more extensive integration of these methods to train the recognition of tactical patterns and battlefield situations.

Maintain the Common Picture

This section identifies several key issues related to maintaining the common picture in particular, and training for pictorial communication and information management in general. Basic research issues for information management training include how to provide the training, assess performance, and give feedback in an effective and efficient manner. For this report, these issues are summarized as the need to develop a digital communications model of the required information

exchanges within a unit, such as a battalion or brigade. A second issue raised is the need to integrate this communications model with related digital technologies, namely warfighting simulations and C⁴I systems, to provide training in realistic job and battlefield settings. The third and final issue considered is to determine how to apply this integrated technology to address multi-level training.

Corresponding method recommendations for each of these issues are provided. These method recommendations are based on reviewed methods for training information management skills and applying digital models to make that training more effective and efficient. Before providing these method recommendations, therefore, background training issues and methods related to information management are reviewed.

The battlefield situation depicted on a C⁴I display is a collaborative soldier-computer product. Maintaining the common picture, a current and accurate depiction of a dynamic battlefield, is a collaborative soldier-computer process. This process entails a host of intersystem and intrasystem information exchanges, and is a challenging information management task. With the less advanced C⁴I systems currently fielded, the challenge falls heavily on soldiers. Training methods are sorely needed to help soldiers maintain a common picture of the battlefield on their C⁴I displays.

"What is the process of maintaining the common picture?" was a key question raised by the Army's Joint Venture Campaign Plan to leverage digital technologies for force and training development (DA, 1996a). Recall that one answer from Focused Dispatch was swivel-chair integration--manual transfers from one C⁴I system to another--due to incompatible C⁴I systems (U.S. Army Armor Center, 1996). A more useful answer may require a detailed analysis and understanding of the communications required between combatants, supporters, and their C⁴I systems.

The Army's experience with digital technologies has strongly reinforced the need to better manage information. The AWEs have repeatedly found that digital C⁴I systems can impose substantial and detrimental amounts of information on warfighters and supporters (U.S. Army Armor Center, 1994; 1996). Similarly, early testing on the Longbow Apache helicopter that is leading Army aviation into the information age, concluded that increased information from digital sensors, displays, and communications makes information management a *critical* combat skill (Snook, 1997).

Across private, commercial, and military sectors, digital technologies are becoming synonymous with information overload. In essence, digital technologies expand our access to, and *accountability* for, more information. Given our inexorable reliance on and alliance with digital information technologies (Negroponte, 1995), we must devise better ways to manage information and train information management. "Better education and training, devoted to information processing under stress and in environments characterized by uncertainty, are needed to develop the necessary skills to handle these information-rich situations" (Alberts, 1996, p. 32).

The military has established methods and techniques for managing information and workload, such as standing operating procedures (SOPs), drills, planning, rehearsal, and training (National Research Council, 1997). These standard information management techniques should be adopted and adapted, where appropriate, as additional methods are developed to manage digital information. For example, Focused Dispatch developed a prototype digital SOP that documents numerous procedures for managing digital information (U.S. Army Armor Center, 1996). The primary concern here, however, is devising new digital methods and techniques for training information management and maintaining a common battlefield picture.

One example of a part-task method for training digital information management is the use of automated message servers to send digital reports to C⁴I system operators (Lickteig & Emery, 1994). Methods for this example included SME development of message sets that varied information amount and relevance for an approved training scenario to provide operational realism. During an exercise, these messages were automatically delivered at a realistic rate to each participant's C⁴I system located in a virtual tank simulator. Information management tasks required the participants to process the messages for a subsequent situational awareness task, and also relay as appropriate any of the messages received to surrogate members of their unit at higher, lower, and adjacent echelons. A follow-on effort developed and implemented a prototype information management training program for this method, and automated a performance feedback approach based on expert analysis (Winsch et al., 1994). More recent adaptations have extended this individual training method to small group staff training (Koger et al., 1998).

Another example is the team model trainer (TMT) developed by Duncan et al. (1996). Although the TMT addressed predominantly verbal communications, its innovative methods exemplify how digital technologies might be applied to training. Based on an expert model of team member communications and activities in a Combat Information Center, TMT was used to train team members individually, prior to small group and collective exercises.

The TMT runs on a stand-alone digital workstation. In addition to simulating team communications and actions, a TMT workstation provides additional information about the roles of team members, team relationships, the information requirements of team members, and the temporal patterns of team communication. One product from the TMT model is a team communication matrix that identifies communication channels and content among team members. A related product, of special interest, is a simulated counterpart of this matrix that visually depicts the flow and pace of communications among team members on the trainee's TMT workstation.

The TMT can run as either a closed- or open-loop model that supports observer or performer mode training, respectively. As an observer, the trainee receives a visual and aural demonstration of expert team performance on a training device that emulates an operator's display and plays prerecorded verbal communications. As part of this observer training, TMT mimics the actions and communications for the trainee's duty position. As a performer, the trainee can assume any team member role, and then respond with the actions and communications for that duty position as the model simulates the actions and communications of other team members. The trainee can also start and stop the simulation at any time for help or additional information, or replay the scenario to review or rehearse selected events.

After selecting a team position and mode (observer or performer), the trainee receives and reviews a situation update tailored to the position selected. The trainee then selects an event from a scenario event list provided on the display and the simulation unfolds from that point of the scenario. During the simulated scenario, the trainee's TMT display depicts and identifies the stations for all six team members in the Combat Information Center. Team actions and communications are depicted as an interactive graphic in which each duty position depicted on the trainee's workstation highlights as that position communicates or acts. The display also depicts a timeline of the scenario with appropriately sequenced action and communication boxes that highlight at the appropriate time.

A final example of methods pertinent to training and maintaining a common picture is an ongoing effort to improve after action reviews (AARs) for units equipped with C⁴I systems (Brown, et al., 1996). This work is designed to automate, at least partially, training analysis and feedback methods for the collective AARs that generally follow unit level training exercises. Two pertinent method aspects of this work are noted.

First, their methods capitalize on the composite database that underlies a C⁴I display. To avoid the labor and delays associated with videotape comparisons of the C⁴I displays for AARs, their design concept stresses automated reconstructions and comparisons of C⁴I display content. Second, these comparisons target the graphical features depicted on C⁴I displays. This work is a basis for this report's working example of automated pictorial comparisons from instrumented C⁴I systems. Method recommendations on multi-level training will examine how automated pictorial comparisons might be used for individual, small group, and collective training.

Develop a Communications Model

Fundamental research issues for information management training include how to provide the training, assess performance, and give feedback in an effective and efficient manner. Providing training is a multi-level requirement that includes individual, small group and collective training requirements. Performance standards of required information exchanges are needed to assess performance. Given standards in adequate detail and format, the question becomes how to apply such standards more easily and evenly to assess training and provide feedback?

A recommended method to address these issues is tailored to this report's focus on training pictorial communications: develop a common picture communications model. This recommendation equates to a computer-based model that simulates the required information exchanges among all unit members during the course of a training exercise. This model does not yet exist, but its primary features are described to clarify its training applications. To aid this description, the term Common Picture Communications Model (CPCM) is coined to identify this model. Although specification of CPCM is not attempted here, its design is based heavily on the communication models of Duncan et al. (1996) and Laughery and Corker (1997).

As a basis for CPCM design and development, structured and realistic tactical scenarios are recommended, such as the FXXITP exercises. The detailed specification of the FXXITP exercises and their delineation of scripted events during the exercise provide a solid foundation for

building a communications model. The model should initially be a battalion-level development, with subsequent extension to brigade level. A FXXITP-based approach also capitalizes on an earlier recommendation to use these exercises for eliciting user information requirements. Recall that these knowledge elicitation methods were designed to identify required information exchanges within a unit and included both C⁴I digital and voice radio communications. Although digital exchanges are key to CPCM, it should include voice radio communications for information requirements not directly supported by the C⁴I systems modeled, for example FBCB².

In essence, the required information exchanges identified by SMEs would be implemented in a computer-based model that simulates the flow of information exchanges among the FXXITP-based duty positions equipped with C⁴I systems. Based on SME inputs, the CPCM represents an expert model that represents an optimal flow of information among the members of the unit. This multipurpose model could be used to demonstrate information exchanges and to generate criterion-based product and process examples for training analysis and feedback on C⁴I battlefield depictions.

Although an expert version of the CPCM has unique advantages, it entails substantial costs. Therefore, a more automated method for developing CPCM is briefly described. Virtual simulation has developed and effectively used software that emulates the information exchanges between modular semi-automated force (ModSAF) entities, such as combat and support vehicles, and delivers these intersystem communications to soldiers equipped with C⁴I systems (Elliott, Sterling & Lickteig, 1998; Leibrecht et al., 1994). In theory, simulation files designed in accordance with FXXITP structured exercises could be run with completely unmanned simulated entities to develop a "machine" version of the CPCM. Realistically, soldier and SME inputs would still be required to complete and validate this version of a communications model. However, the costs for developing a machine version of this model should be substantially lower than for an expert version. Additional tradeoffs between different model versions, including constructive simulation generation, should be considered, but are not in this report. Subsequent discussion of recommended CPCM training applications is independent of version, unless otherwise noted.

The CPCM should run on stand-alone and networked digital workstations. These stations should emulate both the interface and controls for a designated C⁴I system, and for related computer-based training. For stand-alone configuration, the TMT design provides good examples of how a CPCM workstation might be applied to training (Duncan et al., 1996). The CPCM station would support both observer and performer trainee modes for any duty position included in the unit-based FXXITP training exercise.

Integrate Digital Technologies

Another key method for applying digital technologies to train and maintain the common picture is to link digital training workstations and C⁴I systems with the warfighting simulations the Army currently uses for training. Constructive and virtual simulation are inherently digital, and live simulation with C⁴I equipped units is becoming digital. Digital technologies can effectively integrate these simulation domains (Cosby, 1995). Digital technologies can also effectively link Army simulations with other digital training applications, and the methods recommended stress simulation links to the CPCM. Integration of the CPCM to Army training simulation should

substantially broaden its training potential and provide a foundation for developing a digital training environment.

Constructive Simulation

Relative to other Army training simulations, constructive simulation is more a closed-loop model for training applications. Training benefits from closed-loop models include their ability to: (a) stimulate the training response by serving as an exercise driver; (b) pace training, including above- and below-real time; (c) represent more realistic job settings; and (d) model performance. For observer mode training, a direct time- and event-link between CPCM and a constructive simulation could provide the trainee a broader and more meaningful microworld context of battle simulation. For CPCM performer mode training, a constructive depiction of related battlefield activities could stimulate the responses required by the trainee to maintain a common picture of the simulated battlefield on own and others C⁴I displays.

Virtual Simulation

The soldier-in-the-loop nature of virtual simulation is a potent environment for training and assessing soldier performance (Fletcher, 1994). Human interaction can dramatically illustrate and reinforce the value of coordination and communication, the value of maintaining a common picture of the battlefield. More powerful training applications are possible with a CPCM model that runs on virtual simulation networks, such as SIMNET, and is synchronized with the entities simulated on virtual battlefields. Notably, compatibility with virtual networks is almost a "given" for machine versions of CPCM generated in virtual simulation. The CPCM stations could also be hosted on simulated C⁴I systems in training simulators to immerse trainees in more realistic battlefield settings (Alluisi, 1991).

Individual training might use the CPCM to send reports from a FXXITP exercise to the trainee in a C⁴I simulator who would process the information received and simultaneously perform other operational tasks during the simulated exercise. Small group training might network C⁴I systems in multiple simulators to the CPCM. Training exercises could require small groups of trainees to interactively maintain relevant portions of the common picture on own and others C⁴I displays. Exercise extensions might again require trainees to simultaneously perform their other operational tasks during the simulated exercise. Collective training applications of the CPCM might address before and after phases of a collective training exercise. Before a training exercise, a unit might use the CPCM to rehearse the flow of critical or priority information by element, source, and path. After the exercise, the CPCM's examples of information flow and C⁴I common picture snapshots could support automated training analysis and feedback for collective AARs.

Live Simulation

Live simulation may be the Army's most demanding and realistic training venue and the most difficult for training delivery, analysis, and feedback. Moreover, a recent analysis of live force training requirements on the digital battlefield notes that C⁴I-based training increases the training analyst's load and forces a faster feedback process to provide meaningful training

experience (U.S. Army Training Support Center, 1996). In particular, this analysis stresses that training *feedback overload* must be avoided for C⁴I-based live training. The computer-based nature of C⁴I systems could embed training into digital combat and support systems to enable on-board training for live simulation exercises (Morrison & Orlansky, 1997). The CPCPM might represent a module in an embedded training package for C⁴I systems. The need for C⁴I systems to include a simulated model for training and mission rehearsal is frequently cited (Coe, Madden, Mengel, & Wright, 1997). As both a stand-alone and networked module, this embedded information management model could be used to train pictorial communication.

Synthesized simulations--a mix of constructive, virtual, and live simulation--might use CPCPM linkages to help integrate training delivery, analysis, and feedback across diverse units in a variety of ways. First, the overall METT-T organization of the methods provides a common and coherent framework to support training before and after simulated exercises. Second, feedback overload might be avoided by presentation formats based on pictorial comparisons of actual versus model performance. Also, the common picture's integration requirements might effectively illustrate and reinforce the informational dependencies between synthetically linked trainees who might be physically dispersed at remote training sites.

Develop Multi-Level Training

Information management training addresses relatively high-level skills, particularly with the increased amount and complexity of information introduced by digital technologies, such as C⁴I systems. It presumes lower-level C⁴I skills such as basic procedural skills to operate or manipulate the system via the interface controls. It presumes the recognition skills to understand the battlefield patterns and situations depicted on a C⁴I display. Information management skills should also extend to understanding the *possibilities* of a C⁴I system or systems for mission accomplishment (Gattiker, 1990). While the CPCPM might be used to train all of these supporting skills, the primary focus here is on training to maintain a common picture.

By design, the CPCPM model provides training analysis and feedback on trainees' ability to maintain a common picture. As a model of unit-level required C⁴I information exchanges, the CPCPM database should closely approximate the composite database of soldier-computer interactions required to maintain an accurate depiction of the battlefield situation during the training exercise. The methods recommended stress, therefore, that discrepancies between the trainees' and the model's process and products could be automatically detected and graphically highlighted. The following method recommendations integrate and apply the digital technologies of CPCPM and Army warfighting simulations to individual, small group, and collective training.

Individual Training

The potential of applying digital technologies such as CPCPM to individual training on digital systems seems high compared to TMT's application to analog training. For training to maintain a common picture on a C⁴I display, the required information exchanges are almost exclusively digital. The multipurpose nature of a digital workstation for such training is exemplified by its ability to configure as a generic training workstation and/or a C⁴I interface.

More specifically, a portion of the CPCM workstation could be configured to mirror the display and controls of the trainee's C⁴I system, such as the FBCB² system. This area of the CPCM workstation would emulate the functionality of the trainee's C⁴I interface, for both observer and performer modes.

For observer mode training, the CPCM might initially provide trainees an overview that epitomizes the information management requirements and activities for their duty position and other members of their unit. This training would require configuration of the CPCM display to depict multiple duty stations or platforms sending and receiving messages. Vehicle and unit icons might be tactically arrayed on a C⁴I map display and move in accordance with the exercise's dynamic battlefield situation. The CPCM interface could visually depict and highlight the flow, pace, and content of communications among the vehicles and duty positions depicted during a FXXITP exercise.

Configured to emulate a C⁴I interface, on the other hand, a CPCM workstation could mimic the human-computer interactions required for the trainee's selected duty position. As CPCM messages from a simulated FXXITP exercise were received, for this observer mode training, the simulated interface would open the messages and post associated graphic content to the tactical display's battlefield representation. When appropriate, the simulated interface might also manipulate map scale and zoom levels to provide an adequate situational context for message processing. As C⁴I messages were sent by the CPCM from the trainee's workstation, the interface would continue to mimic the soldier-computer interactions required for distributing this information. If this CPCM work station was embedded in a virtual simulator and linked to a virtual exercise, then the required information exchanges could be demonstrated in a task-based battlefield setting that the trainee could stop, review, and replay as desired.

For performer mode training, the simulated C⁴I interface would still receive and depict CPCM communications but require trainees to make the inputs for their respective duty position. The trainee would make all the human interactions required to receive and display battlefield information on the simulated C⁴I display. At the same time, the trainee would perform the procedures required to originate or forward communications, as appropriate, to other surrogate members of the unit.

The CPCM workstation design should also customize training to address particular information management needs. The trainee's designated duty position and the information exchanges relevant to that position might be a primary training focus. Information exchanges related to other key duty positions, such as the CCIR or PIR, might be a more specific focus of training. Customization could also allow a METT-T breakout of information types, for example, to selectively highlight the flow of enemy information between the trainee's duty position and key superior and subordinate positions during the course of a FXXITP exercise. Similarly, an event-based focus on required communications might help the trainee anticipate and understand workload variations during the course of a FXXITP exercise.

Automated training analysis routines could compare the trainee's performance with that of the CPCM, and prepare performance feedback products available during and after the training

exercise. Training objectives and feedback should stress how unit members are dependent upon one another to maintain an accurate and relevant picture of the battlefield situation. Feedback formats should pictorially highlight the unit's dependence on the information controlled by the trainee. Feedback might provide pictorial comparisons between the trainee's C⁴I display and the model-generated displays of other surrogate unit members. Other feedback examples might highlight information that should have been available to the trainee's superiors and subordinates that was not provided by the trainee, or compare trainee's versus model timelines for exchanging information.

Small Group Training

Collaborative requirements to maintain a common picture of the battlefield situation should be stressed as training progresses from individual to small group level. Unlike TMT, networked CPCM workstations should link multiple trainees in small group training exercises. Many of the methods recommended for individual training can be readily extended to include multiple trainees. For small group training the CPCM could depict a subset of other duty positions to model information exchanges within a designated group. Training methods could apply the CPCM open-model to allow two or three trainees to co-participate in the same information management exercises. As an automated message server, the CPCM would send digital reports to this small group of trainees who would be required to originate and relay, as appropriate, C⁴I-based communications to each other as well as other surrogate members of their unit.

Training objectives for small groups should stress information exchanges required between the current trainees. Accordingly, training analysis and feedback might concentrate on unmet information requirements or delayed communications based on the information management performance of the trainees. Feedback formats might include display snapshot or timeline comparisons, or instances where trainees relayed redundant information to other members of their unit. As with individual training, all feedback might be structured by phases and events from the FXXITP exercise used for training.

Collective Training

Collective training generally extends the training audience to include all, or a substantial portion of, unit members interacting in a simulated operational setting. Unit size and exercise objectives may vary substantially, however, for a collective training audience. The VTP-based exercises, for example, include platoon and company tables that are mission segments extracted from larger unit full-mission operations. Similar tables are recommended to focus training objectives and feedback on the information management requirements for units equipped with C⁴I displays. The expert analysis of FXXITP-based information requirements, previously discussed, should help formulate training objectives and structure collective training exercises and exercise segments directed at maintaining a picture of the battlefield situation on trainees' C⁴I displays.

Collective training provides an ideal forum to understand and practice the collaborative process of managing information. To minimize disruption of a collective exercise, however, training methods for information management that apply before and after the unit conducts a

mission or table are recommended. Prior to a collective exercise, the CPCPM could support training objectives for information management products and procedures. Large-scale digital displays with CPCPM could demonstrate and illustrate collective process and product examples for managing information to maintain a picture of the battlefield. Methods for demonstrating process and illustrating products could be used to refresh or rehearse information management skills, prior to the collective exercise.

For example, a key training requirement for information management is an appreciation of the overall digital communications network structure. Past digital training experiences have stressed that this is a critical but neglected aspect of training, and that alphanumeric routing matrices are not an effective format for conveying such training (Elliott, Sanders, & Quinkert, 1996). Collective training, in particular, might use CPCPM to pictorially illustrate the flow of information across the unit's digital architecture and underscore its importance for successfully completing the upcoming training exercise. Key decision and coordination points in the training exercise, for example, might be identified and depicted in their anticipated battlefield context on a large-scale C⁴I display. The information requirements associated with each of these points by element, source, and path might be identified and pictorially highlighted.

After the exercise, digital training applications might adapt some of the automated training analysis and feedback methods, previously described, for unit-level AARs. Methods for AARs should stress automated reconstructions and comparisons of C⁴I displays within the unit, or with displays generated by the CPCPM model. These methods should directly target the graphical features depicted on C⁴I displays.

Product feedback examples include automated snapshot comparisons between the C⁴I displays of any unit trainees at any time during the training exercise that might disclose important discrepancies, such as the location of friendly and enemy vehicles, obstacles, or contaminated areas. Product examples might also include automated comparisons of C⁴I display content based on unit performance with CPCPM products. Overall, product feedback should stress pictorial formats that automatically highlight potential problems in the unit's effort to maintain a picture of the battlefield.

Process feedback might address problems related to discrete events at key moments during the exercise or to the more continuous flow of information across the exercise. The information flow formats used before the exercise to model information exchanges could be compared with the unit's actual performance during the exercise. Or for information elements identified as critical by the unit before the training exercise, the AAR could automatically illustrate the flow of this information during the exercise. Information exchanges supporting key decision points, for example, during the exercise could be graphically illustrated on a dynamic timeline by information element, source, and path. Overall, process feedback should stress pictorial formats that depict the process, the problems identified, and sample solutions.

Method Summary

This method section identified three main areas of research directed at the pictorial communication of battlefield situations on C⁴I displays. These research areas were centered on common picture training and evaluation requirements: define, communicate, and maintain a common picture of the battlefield. For each of these areas, a set of research issues related to the requirement were identified, and then corresponding training and evaluation methods were recommended to help address the issues raised, see Table 1.

The methods recommended were based on the authors' review of documented methods and the relatively unique capability of digital information systems, such as instrumented C⁴I systems and military warfighting simulations, to synthesize training and evaluation. Background information provided more detailed description of and reference to the methods recommended. The method recommendations adapted a relatively integrated set of training and evaluation methods to more directly address the Army's C⁴I research issues identified in this report.

CONCLUSIONS ON METHOD INTEGRATION

This section describes how the training and evaluation methods recommended in this report, in concert with digital technologies, might help design and develop a digital training environment. Key training and evaluation considerations for this environment focus on the need to pictorially communicate the battlefield situations depicted on digital displays.

Design and Develop a Digital Training Environment

By design, a digital training environment is the recommended medium for integrating and implementing the methods recommended. Figure 2 provides an overview of how methods directed at the pictorial communication of battlefield situations on C⁴I displays might be integrated in a digital training environment. This figure portrays the use of a unit-level digital communications model linked to simulation drivers, virtual (ModSAF) and constructive (Janus), and C⁴I workstations for individual, small group, and collective training.

Although a digital training environment should entail all forms of Army training simulation, the discussion here concentrates on the use of virtual simulation. This emphasis on virtual simulation is consistent with the methods recommended for defining, communicating and maintaining a common picture of the battlefield on C⁴I displays. Moreover, the soldier-in-the-loop nature of virtual simulation affords the human interaction for meaningful training.

The conclusions on method integration stress that the digital nature of virtual simulation linked to C⁴I displays provides an environment that may effectively synthesize training and evaluation. First, this section describes how the methods recommended and a digital training environment support training. Key considerations include the identification of training requirements, training development and delivery, and training analysis and feedback. Measurement is essential to training analysis, feedback, and evaluation. The methods recommended have

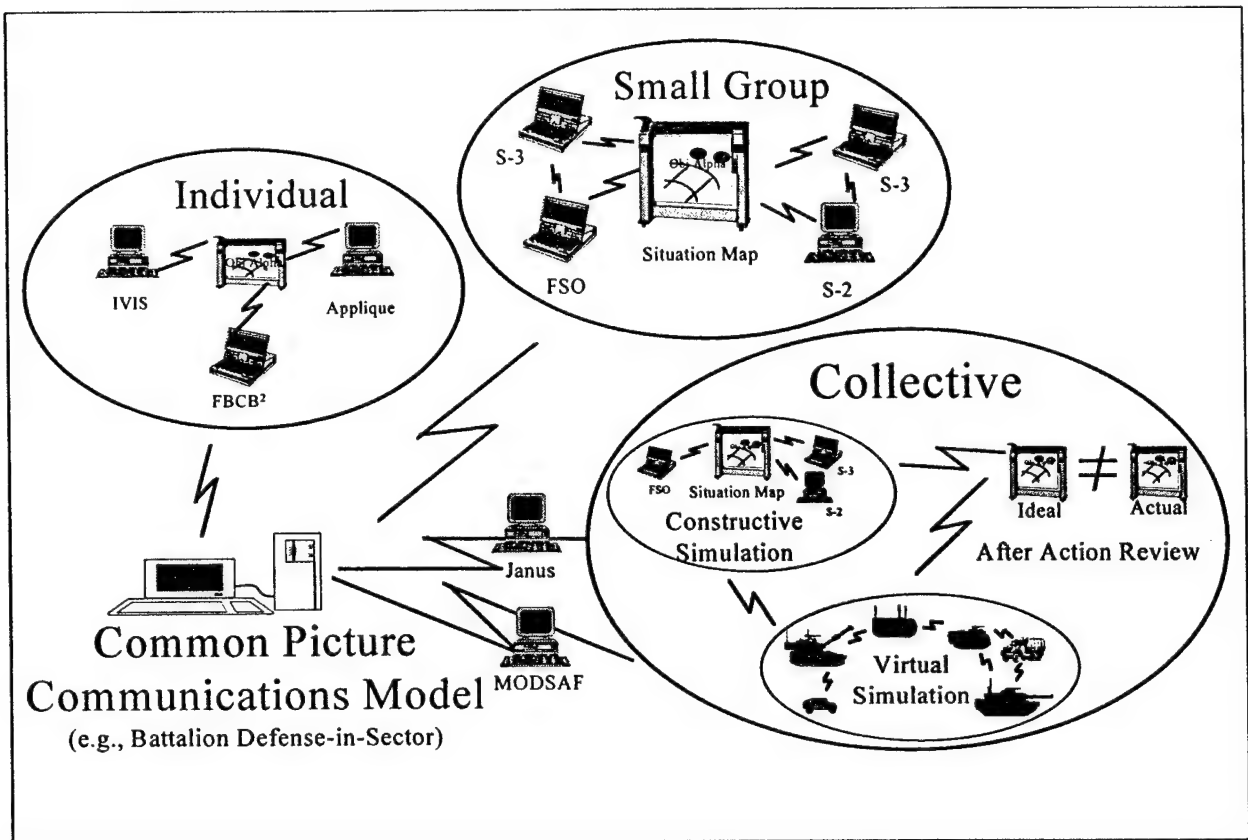


Figure 2. Integration of recommended training and evaluation methods in a digital training environment.

stressed an empirical approach to training based on instrumented C⁴I systems. Virtual simulation's unique potential for training and evaluation is noted by Fletcher (1994):

By instrumenting the electronic battlefield and issuing in an accessible, digital format, comprehensive and absolutely accurate data on the physical characteristics and actions of entities participating in an emerging task situation and by providing powerful new display capabilities...that can replay as often as necessary and from any desired viewpoint the behavior of all the collectives involved, networked simulation both enhances the most promising of our measures of collective behavior and makes them practicable. It provides the foundation for a measurement system that should substantially advance our assessments of crews, teams and units in both military and nonmilitary settings. (p. 268)

Finally, this section describes how the methods recommended and a digital training environment support performance evaluation. Key considerations include machine, soldier, and soldier-machine performance.

Training Considerations

This section describes how the methods recommended in this report might support training considerations for the design and development of a digital training environment.

Training Requirements and Training Development

Training requirement identification for defining, communicating, and maintaining a common picture of the battlefield on C⁴I displays is a key aspect of the methods recommended for training pictorial communication. Implementation of these methods in a digital training environment should refine training requirements and training development, and foster the environment. Methods for defining the common picture, for example, addressed determination of the METT-T informational requirements of combatants and supporters as a basis for identifying C⁴I-based training requirements. These methods primarily elicited expert's knowledge on the informational requirements for duty positions within a battalion or brigade. Knowledge elicitation was based on a process trace of soldier performance during FXXITP exercises conducted in virtual and constructive simulation.

Methods for communicating the picture depicted on C⁴I displays stressed the training requirement to shape the mental model of trainees to better understand the battlefield representations depicted. These methods identified relatively unmet requirements to train battlefield pattern and situation recognition, and their C⁴I representations in particular. Implementation of these methods should result in a detailed analysis of the types of battlefield patterns and situations that should be trained. The training methods recommended, such as consistent practice, include guidelines on how that training should and should not be developed.

Methods for maintaining the battlefield picture depicted on C⁴I displays also addressed training requirements based on an expert analysis of a unit's informational requirements. That analysis should provide relatively precise specifications of training requirements, to include the type of METT-T information required by each duty position and the information exchanges required to maintain a common picture across the unit. Method background also identified the training requirement to provide a mental model for managing information that reflects the communication capabilities of their actual C⁴I systems and their unit's digital architecture. The methods recommended how a communications model could be developed to help form mental models of information exchange at individual, small group, and collective levels.

Training Delivery

This report's background discussed how digital technologies impact the pillars of Army training--the institution, the unit and self-development. A major shift in training delivery pillars is occurring based on the ability of digital technologies to provide distance learning and create a

virtual classroom. Enabling assumptions are that digital technologies can deliver training to any individual at any location, and simulate a work context such as a battlefield situation. Notably, this "environment" without walls includes a mix of constructive, virtual, and live simulations. How a digital training environment might balance concerns about training effectiveness and efficiency, the benefits and costs of delivering customized training, was also discussed.

The recommended methods for communicating a common picture stressed how digital technologies can represent and link the trainee's mental model with the microworld environments reflected in C⁴I displays and virtual simulation. The recommended pattern and situation recognition methods employ these technologies to deliver training in the form of consistent practice to improve performance. Other methods leverage the ability of digital technologies to enable learner-controlled transformations and augmentations of microworld representations to help trainees understand and respond to the battlefield situations depicted on C⁴I displays.

The methods for maintaining a common picture were deliberately centered in a digital training environment (see Figure 2). Methods for individual, small group, and collective training using the CPCM communications model were described. Methods for delivering this training stressed formats that depict C⁴I display products, and mimic the process of information exchange by which those products are created and maintained.

Training Analysis and Feedback

The training methods recommended consistently employ digital technologies to provide training analysis and feedback for pictorial communication training. Virtual simulation, in particular, establishes a comprehensive database on the actions of simulated entities participating in complex and dynamic training exercises (Fletcher, 1994). Instrumented C⁴I systems establish a comprehensive database on the information exchanges of real soldiers that result in battlefield depictions on their tactical displays. Coupled in a digital training environment, these technologies provide an unprecedented capability to automatically record and analyze training performance, and to develop and provide objective feedback.

A summary indication of how digital methods might provide training analysis and feedback is the characterization of the battlefield situation depicted on C⁴I displays as a meaningful, measurable, and collaborative product. A composite database of the elements depicted on the tactical display by source and path represents a measurable product achieved through collaborative information processing and management. The methods recommended repeatedly apply this C⁴I database to analyze individual, small group, and collective training exercises. The focus on pictorial communication of C⁴I-based battlefield situations exploits this database to generate objective training feedback at both a process and product level. A working example of product feedback was automated snapshot comparisons between the C⁴I displays of various unit members that might disclose important discrepancies in the battlefield situations depicted.

These recommended methods were also designed to provide training feedback that is meaningful. The METT-T organization of methods may serve as a meaningful framework for structuring feedback in a manner that reinforces and shapes the mental models of military trainees.

Methods for communicating the common picture stressed analysis of a trainee's component skills, such as pattern recognition, to build situation recognition and response skills. Methods for maintaining the common picture were designed to assess and promote an understanding of how trainees' performance contributes to the unit's informational requirements, and overall mission accomplishment. Feedback methods on information management performance, for example, pictorially highlighted training deficiencies at both the process and product level. Moreover, all of the methods recommended were grounded in representative FXXITP training exercises and actual or simulated C⁴I systems to provide a meaningful context for training.

Evaluation Considerations

This section describes how the methods recommended in this report might support evaluation considerations for the design and development of a digital training environment.

A digital training environment should render feedback mechanisms to evaluators and bill payers to justify the training and environment provided (Deitchman, 1993). The digital technologies that comprise this environment should enable the controls required to develop systematic procedures and standardized training conditions to evaluate performance. This discussion of performance evaluation in a digital training environment is limited. The intent is to indicate how the methods recommended for training pictorial communication on C⁴I displays apply to performance evaluation. The recommended methods target the collaborative potential of soldier-machine systems. The emphasis here is that performance evaluation, made possible by a digital training environment, is essential to achieving that potential.

Machine Performance

Training on C⁴I systems is directly dependent upon the functional capabilities and operating procedures associated with this equipment. Training requirements and programs for C⁴I systems are best based on a detailed understanding of the required interactions between soldiers and C⁴I machines. A more expansive notion of a digital training center, therefore, might include evaluations of machine performance to determine capabilities and support training (Coe et al., 1997).

The need for more precise specification and testing in the development of C⁴I systems was reflected by the call for MOEs on hardware performance (J. Hiller, personal communication, December 9, 1996). The functional description for FBCB² also stresses objective assessments of machine performance:

... An objective assessment of the information management process at each OPFAC [operational facility] using a standard set of analysis tools which eliminates any subjective variations in defining the operational requirements for that specific OPFAC. A quantifiable assessment of how this information management function is to be performed in terms of specific operating parameters. (U.S. Army Armor Center, 1997, p. 31)

Method recommendations for developing C⁴I display codes may result in MOEs reflecting machine performance, and directing machine performance improvements. Such measures should provide an objective basis for identifying and quantifying met and unmet C⁴I requirements, and help substantiate the impact of requested improvements. The METT-T organization of these C⁴I display codes may provide a meaningful structure for evaluating and reporting C⁴I system performance. Related methods for evaluating C⁴I system performance in virtual simulation are also recommended (Heiden, Sever, Smith & Throne, 1996).

Soldier Performance

Evaluations of soldier performance as a result of training are required to assess and improve the training provided. More global evaluations of soldier performance are needed to assess training effectiveness and efficiency, particularly in terms of cost tradeoffs. More directed evaluations of soldier performance are needed to improve training in terms of skill acquisition, retention, and sustainment. While these soldier performance evaluation concerns are common to military training programs, the Army's growing reliance on C⁴I systems reinforces and extends these concerns.

The recommended methods repeatedly stress an empirical approach to training analysis that should directly support evaluation concerns. The core to this approach is the composite database of information elements depicted on the tactical display that provides tractable links to this product, and the soldier performance process by which this product is generated and maintained. Implementation of these methods with instrumented C⁴I systems in virtual simulation should overcome many of the limitations associated with observing and measuring soldier performance, particularly in combat vehicle settings. While constructive simulation *requires* input data on soldier performance, virtual simulation affords this data via soldier-in-the-loop performance (Deitchman, 1993). Virtual simulation also provides a powerful set of tools and utilities for structuring evaluation conditions to attain more robust findings on training efficiency and effectiveness.

Soldier-Machine Performance

Perhaps an ultimate function of a digital training environment is to support the evaluation of soldier-machine performance. Evaluation of a complete system, soldiers and machines, might appear to exceed the role of an environment dedicated to training. This notion of a digital training environment is admittedly broad and pragmatic; there may be no practical alternative for such evaluations.

These methods accentuate the cumulative effects in soldier-machine performance anticipated by coordinated improvements in both soldier and machine performance. Methods recommended for knowledge elicitation, for example, were designed to match machine characteristics to soldiers, to shape C⁴I representations to soldiers' mental models. Training methods for communicating the common picture were designed to match soldier characteristics to machines, to shape soldiers' mental models to microworld C⁴I representations. A summary example of this emphasis on collaborative performance is the characterization of soldiers and C⁴I systems as joint cognitive systems. The training methods recommended entail objective and

automated measures for evaluating the products and process of soldier-machine interaction. These methods and measures should support evaluations of soldier-machine performance in an environment that provides realistic battlefield settings. For a programmatic example of how virtual simulation can be used to evaluate soldier-machine performance as a function of C⁴I systems, see Leibrecht et al. (1994).

SUMMARY

The U.S. Army is focused on information-age warfare and the exploitation of information technologies to maintain a dominant force. At a visionary level, this is a force of cyber warriors with humans and computers allied as a joint cognitive system. An objective that epitomizes this exploitation is the provision of a common and relevant picture of the battlefield situation to all warfighters and supporters. Training and evaluation methods to improve soldier-computer performance are needed to achieve the Army's information age objectives. This report identifies a set of research issues and provides corresponding method recommendations to help realize the potential of C⁴I systems to train and empower an information-age force.

The approach was based on several key assumptions. First, computers can and must help solve many of the training problems they create. Second, C⁴I displays should convey needed battlefield information in picture formats the user can satisfactorily receive, understand, and act on. While textual and tabular formats may provide additional detail, a pictorial representation of the battlefield situation is a foremost concern. Third, when a worker's tool is an information technology, such as a C⁴I system, communication between that tool and the worker is critical to their collaborative performance. These assumptions are introduced in this report's title and maintained throughout the report's method recommendations for training and evaluation.

A final assumption is that measurement is essential to training and evaluation. However, direct observation and objective measurement of performance during military training exercises is difficult. A primary method recommendation, therefore, is to instrument C⁴I systems to compile a log of all soldier-computer interactions as an empirical basis for assessing performance and giving feedback. Recommendations on evaluation methods are designed to provide an automatic empirical account of the pictorial elements required for the common picture product and, the process by which those elements are created and maintained. Recommendations on training methods use this objective assessment to provide pictorial feedback on process and product performance.

The report's working example of empirical assessment and feedback is automated pictorial comparisons of the battlefield situations depicted on the C⁴I displays of any or all unit members at any time during a training exercise. Such comparisons are analogous to the "compare document" function for comparing textual products. Instrumented C⁴I systems could readily provide a similar "compare picture" function. Automated comparisons of a company commander's and platoon leader's C⁴I displays, for example, might graphically highlight important discrepancies, or what is uncommon, in their depicted battlefield situations.

The background section reviews some barriers that deter the application of training technology. These barriers include a project versus program approach to training development, a

failure to apply more unique medium capabilities, and a failure to match training content to what trainees already know. This review stresses the relatively unique ability of digital technologies to emulate battlefield situations on a C⁴I display and the mental models of trainees, and then perceptually link these models to train pictorial communication. Digital training implications, both theoretical and practical, are examined to balance training efficiency and effectiveness.

The method section identifies three main areas of research directed at the pictorial communication of battlefield situations on C⁴I displays. These research areas are centered on common picture training and evaluation requirements: define, communicate, and maintain a common picture of the battlefield. For each of these areas, the method section identifies a set of research issues related to the requirement, and then recommends a set of training and evaluation methods designed to help address the issues raised. The methods recommended rely on others documented training and evaluation methods. The contribution of this report, at best, is to document how the methods reviewed might be adapted and integrated to help the Army meet some important C⁴I training and evaluation requirements.

The conclusion section integrates the training and research methods recommended in this report, in concert with digital technologies, to help design and develop a digital training environment directed at pictorial communication. This section stresses that method integration in virtual simulation, in particular, might provide an environment that effectively synthesizes training and evaluation. Key training considerations include the identification of training requirements, training development and delivery, and training analysis and feedback. Key evaluation considerations include machine, soldier, and soldier-machine performance.

The methods recommended in this report are small building blocks in the larger body of training and evaluation research and development required to achieve the anticipated potential of C⁴I systems and the Army's modernization objectives. These method recommendations should help training and evaluation researchers improve soldier-computer interaction and foster the skills needed to understand and maintain a pictorial depiction of a battlefield situation on a digital display. Method implementation will require coordinated efforts between these researchers and the developers of training, training simulation, and digital systems to help the Army design and develop a digital training environment that provides the skills required for an information age force.

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APPENDIX A

ACRONYMS and ABBREVIATIONS

1SG	First Sergeant
AAR	After Action Review
ABCS	Army Battle Command System
ARI	U.S. Army Research Institute
Aves	Avenues
AWE	Advanced Warfighting Experiment
C ⁴ I	Command, Control, Communication, Computer, and Intelligence
CCIR	Commander's Critical Information Requirements
CDR	Commander
COA	Course of Action
Comm	Communicate
CPCM	Common Picture Communications Model
D	Dimensional
DA	Department of the Army
Dir	Direction
DP	Duty Position
EEFI	Essential Elements of Friendly Information
EPSS	Electronic Performance Support Systems
FASTTRAIN	Force XXI Training Methods and Strategies
FBC	Future Battlefield Conditions
FBCB ²	Force XXI Battle Command Brigade and Below
FFIR	Friendly Forces Information Requirements
FRAGO	Fragmentary Order
FSO	Fire Support Officer
FXXITP	Force XXI Training Program
INA	Information Needs Analysis
Info	Information
ISD	Instructional Systems Development
IVIS	Intervehicular Information System
LTIOV	Latest Time Information of Value
METT-T	Mission, Enemy, Terrain, Troops, and Time
METT-TC	Mission, Enemy, Terrain, Troops, Time, and Civilians
MIDAS	Man-Machine Integrated Design and Analysis System
MOA	Memorandum of Agreement
ModSAF	Modular Semi-Automated Forces
MOE	Measure of Effectiveness
NTC	National Training Center
OPFAC	Operational Facility
OPORD	Operations Order
OPS	Operations

PIR	Priority Information Requirements
Recvd	Received
Reqd	Required
ROTC	Reserve Officer Training Corps
S2	Intelligence Officer
S3	Operations and Training Officer
SALUTE	Size, activity, location, unit type, time and equipment
SIMNET	Simulation Networking
SME	Subject Matter Expert
SOP	Standing Operating Procedure
Sync	Synchronization
TF	Task Force
TMT	Team Model Training/Trainer
TOC	Tactical Operations Center
TRADOC	Training and Doctrine Command
USAARMC	U.S. Army Armor Center
VTP	Virtual Training Program
WARNO	Warning Order